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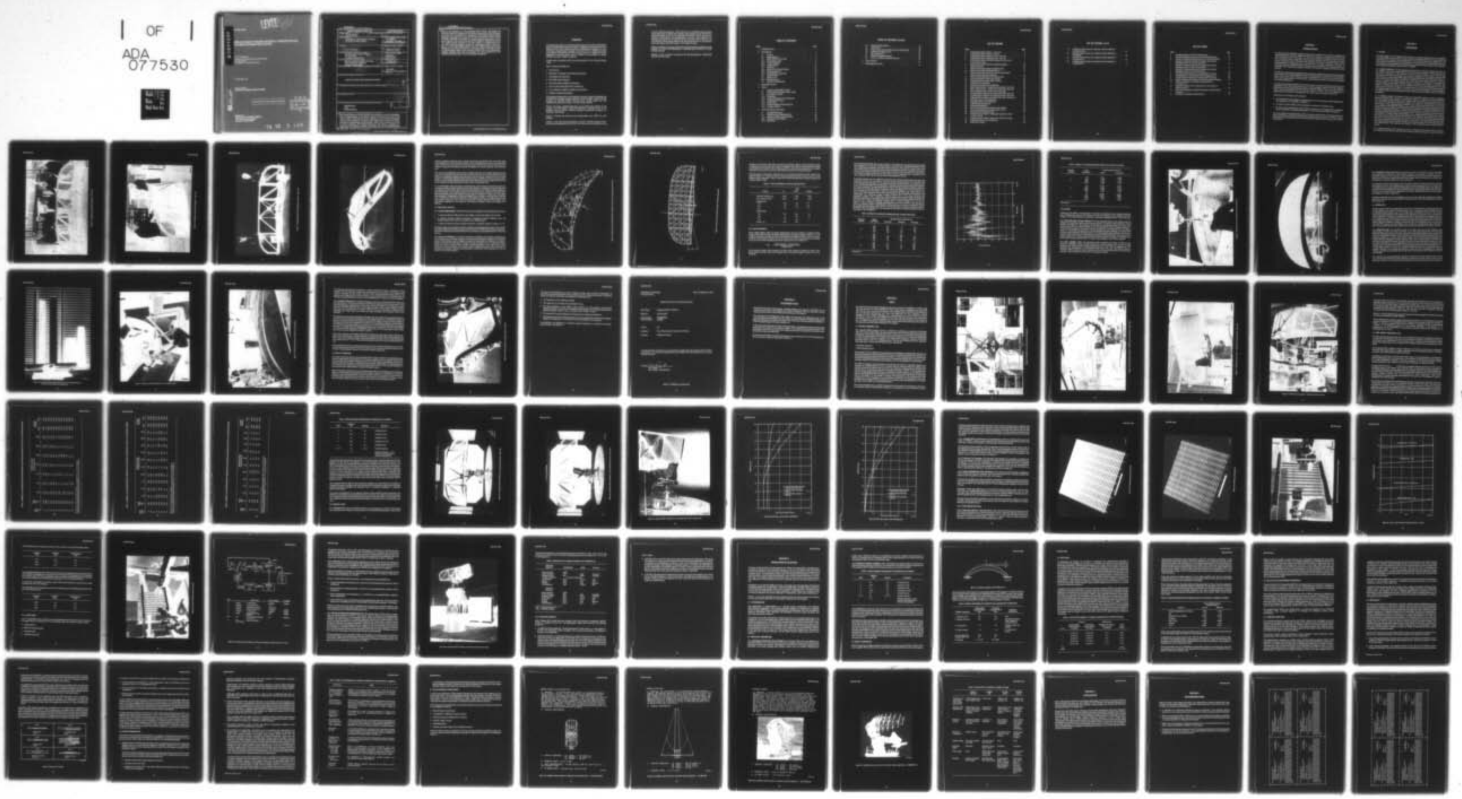

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APPLICATION OF GRAPHITE/EPOXY COMPOSITES FOR THE SPS-10 RADAR REFLECTOR

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1 OCTOBER 1979

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

The General Dynamics Convair Division was contracted to evaluate the applicability of graphite/epoxy on the SPS-10 reflector. This task was a result of the Navy's study to reduce life cycle costs, acquisition costs, and structural weight of Naval antenna systems. The Convair effort began with a study of the RF performance of a graphite/epoxy grating panel, which proved to perform as well as its metal counterpart. We designed, fabricated, and tested a composite prototype unit of the reflector unit for performance approval. The graphite/epoxy

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reflector was mounted on a Navy-furnished SPS-10 spider and pedestal for structural (wind and vibration) and RF pattern range testing. All performance test results met or exceeded Navy specifications. Following testing at General Dynamics, the antenna was sent to the Naval Ocean Systems Center (NOSC), San Diego, California, for extended RF and environmental testing prior to shipboard evaluation. The Convair prototype SPS-10 reflector weighs 66.9 pounds (a 14% weight reduction compared to the metal SPS-10). An applications evaluation study during the program showed that a significantly greater weight savings, i.e., a 20.1-pound weight reduction for a 26% weight savings, and reduced fabrication costs could be realized for a production design of the SPS-10 reflector. The production design would make more efficient use of the graphite/epoxy material, including wind holes and stiffeners and would eliminate all of the aluminum tubes and many of the joint fittings and gussets.

SUMMARY

The General Dynamics Convair Division developed and executed a technical program for the Naval Sea Command intended to upgrade the performance of Naval antenna system. This program involved an applications evaluation of a new technology: graphite/epoxy composite structure for Navy shipborne environment exposure. We selected the SPS-10 radar reflector as a design base for the applications evaluation effort, and the program was developed to design, fabricate, and test a reflector assembly.

Graphite/epoxy composites offer several advantages for Navy antenna systems usage.

Some of these advantages are:

a. Noncorrosive.

b. Resistant to shipborne environmental exposures.

c. 40% lighter than aluminum.

d. 80% stiffer than aluminum.

e. Twice the tensile strength of aluminum.

f. Only 5% the thermal distortion of aluminum.

g. It is conductive; reflective coating is not required.

h. Exhibits excellent fabricability.

This program demonstrates the advantages advanced composite technology has for future Navy antenna systems. Reduced structural weight, coupled with the potential for markedly reduced life-cycle costs, permits larger and more sophisticated antenna structures to be economically feasible.

Section 2 presents a detailed discussion on the design and analysis of this antenna, the cost-effective tooling and fabrication techniques used for its assembly and the quality assurance inspection performed throughout its fabrication and testing.

Section 3 presents the Contract Data Requirements List (CDRL) for this program.

Section 4 covers the testing performed by Convair. Vibration testing to determine natural frequencies up to 100 Hz in all three axes was performed at the

Convair vibrations laboratory. Wind tunnel tests to determine antenna operational performance in high-wind conditions were performed at the Convair low-speed wind tunnel at the Convair Lindbergh Field facility. Finally, electrical performance characteristics of a graphite/epoxy test panel were compared to an aluminum test panel and RF patterns for the composite SPS-10 reflector unit were checked. The prototype reflector unit passed all performance tests satisfactorily and weighs only 66.9 pounds (a 14% weight savings).

Section 5 presents a thorough review of all data and technology gained from this program to evaluate the applicability of graphite/epoxy structures to other antenna systems.

Sections 6 and 7 presents conclusions and recommendations, respectively, derived from this study.

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SECTION 1

INTRODUCTION

In the past, Naval shipborne antenna systems have experienced an in-service problem that required significant attention. Shipborne antennas are subject to a hostile and varied environment that includes salt air and spray, ice, snow, rain, extremes of humidity, shock, and vibration. In addition, there is exposure to ultraviolet (uv) radiation and hot stack gases and their corrosive chemical attack. The relative inaccessibility of antennas sometimes results in their being neglected by maintenance crews. Corrosion may arise from stack gases, salt spray, or electrolysis between dissimilar metals. This may cause the radiating or receiving surfaces to be extremely lossy; resulting in impaired reception, and eventual complete deterioration of the antenna.

The advent of high-strength, high-modulus, low-density graphite fibers has presented unique opportunities in countless applications where these properties are beneficial. One such application is in the area of radar antenna systems. Graphite fibers, when used to reinforce epoxy resin, yield a material that is well suited for withstanding the harsh environment associated with Naval applications.

To meet this technology problem, the Convair Division of General Dynamics Corporation has completed, for the Naval Sea Command, an 18-month program during which they designed, fabricated, and tested a graphite/epoxy SPS-10 radar grid reflector unit. As a result of this program, real and parametric data were derived relative to merits, costs, and application of graphite/epoxy structures for upgrading Naval radar antenna systems performance.

Objectives of this program were threefold:

a. To demonstrate the feasibility of graphite/epoxy for Navy antenna system applications, and compare it to the metallic counterpart.

b. To achieve a lower weight, lower maintenance, and lower cost reflector unit.

c. To derive real and parametric data relative to merits, cost, and application of graphite/epoxy technology for updating performance in the surface-ship marine environment.

The total weight of the graphite/epoxy SPS-10 reflector is 66.9 pounds. All program objectives were accomplished and design and performance specifications were met or exceeded, thereby demonstrating that graphite/expoxy antenna systems are ideally suited for many future Naval installations.

SECTION 2

DISCUSSION

2.1 DESIGN

The final design for the composite SPS-10 reflector required modifications to the originally proposed reflector to meet the wind and dynamic load specifications and remain within the contractual cost restraints. Such modification to the initial design and the additional structural analysis associated with those changes were made possible by minimizing the total tooling investment and streamlining the fabrication and quality assurance tasks. None of the proposed design specifications were waived or modified.

2.1.1 DESIGN APPROACH. Convair designed the deep beam, truss frame support structure for the reflective mesh after considerable study of the structural stiffness requirements and contour control necessary for the reflector. From the structural point of view, three simple parabolic curved I-beams spanning in the horizontal direction was the simplest and most efficient system to control the parabolic shape within small deflection under high loads. Figures 1 and 2 show the as-built reflector, consisting of a reflective mesh, support structure, and a strut system. A simple truss frame between the curved beams was necessary for torsional and lateral stability. Gusset plates and shear blocks at all joints were necessary to provide joint rigidity in bending and torsion and to distribute shear loads through member webs. The tubular strut system in the back of the support structure transmits the distributed bending and tipping loads from the reflector to the aft spider mount arm support. Various design-to-cost decisions affected the final design of these components and are discussed in the following paragraphs.

2.1.1.1 Reflective Mesh. The reflective mesh was assembled using two types of elements: horizontal elements that conform to the paraboic shape of the reflector and vertical elements that are straight. Design selection of the reflective mesh was based on an investigation of the cost of several fabrication techniques available. An eight-ply pseudoisotropic orientation $(0/\pm45/90)_S$ of 5-mil graphite/epoxy (T300/934) tape prepreg was selected for its structural characteristics of strength and stiffness and its lower cost.A fabrication technique that would result in the exterior surface ply (0° ply) being oriented parallel to the parabolic shape was considered but eliminated as being too costly. A flat panel layup was selected. Final trim of the horizontal parabolic elements was accomplished by a water jet technique that reduced costs considerably. To reduce tooling and fabrication costs, a single parabolic template was used for the concave/convex edge of the parabolic element. This resulted in the element width varying from 0.57 inch at the extreme end to 0.77 inch at the centerline. This fabrication technique resulted in no material loss during trimming. No slots were cut in the parabolic elements. Only the vertical members were slotted to simplify the fabrication task and the structural and electrical performance of the mesh did not require a flush horizontal/vertical member concave surface.

2.1.1.2 Support Structure. The support structure is a deep beam, truss frame whose members are built-up I-beam sections and one-piece channel sections (see Figures 3 and 4). All of the

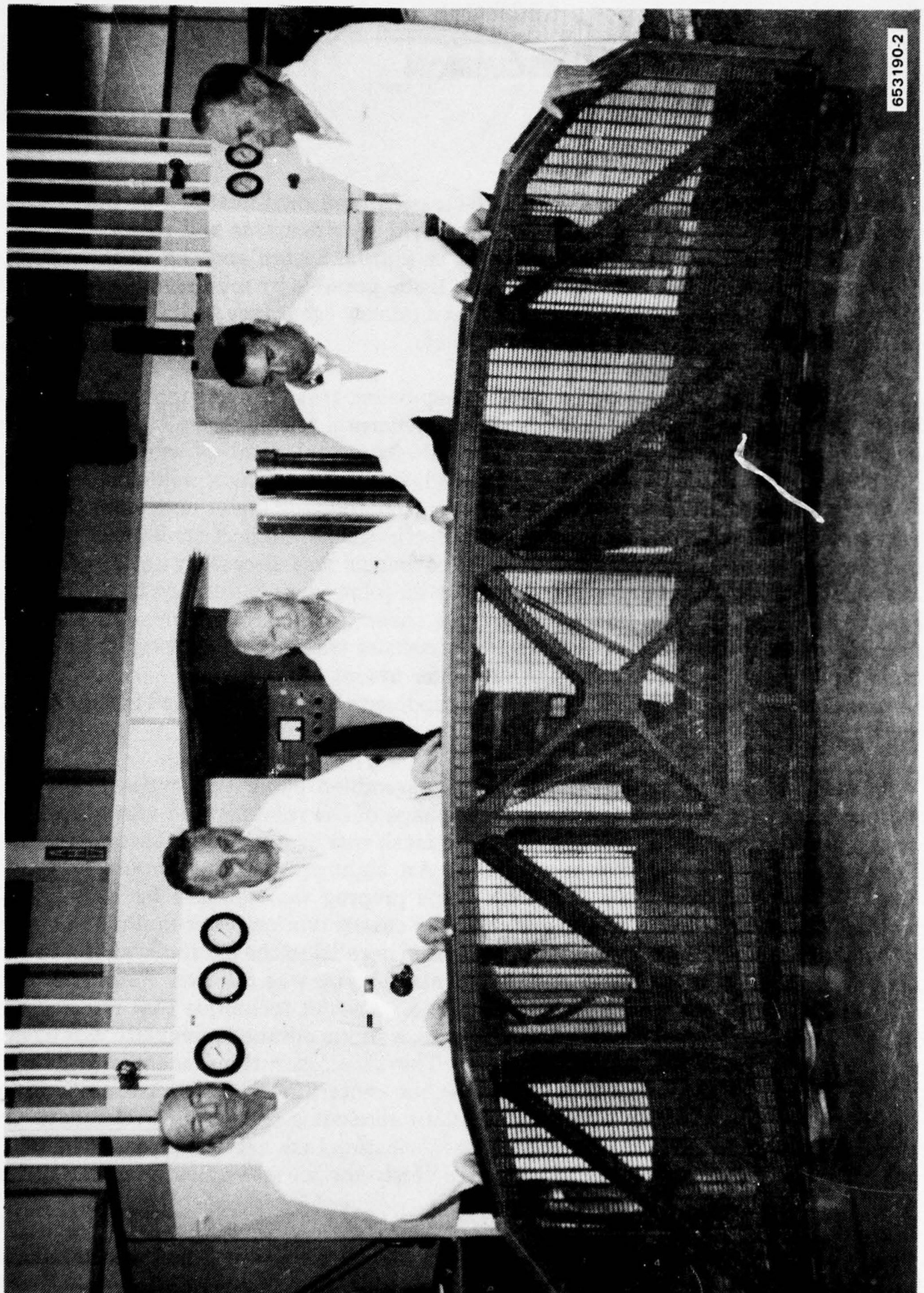

Figure 1. Graphite/epoxy SPS-10 reflector - front view

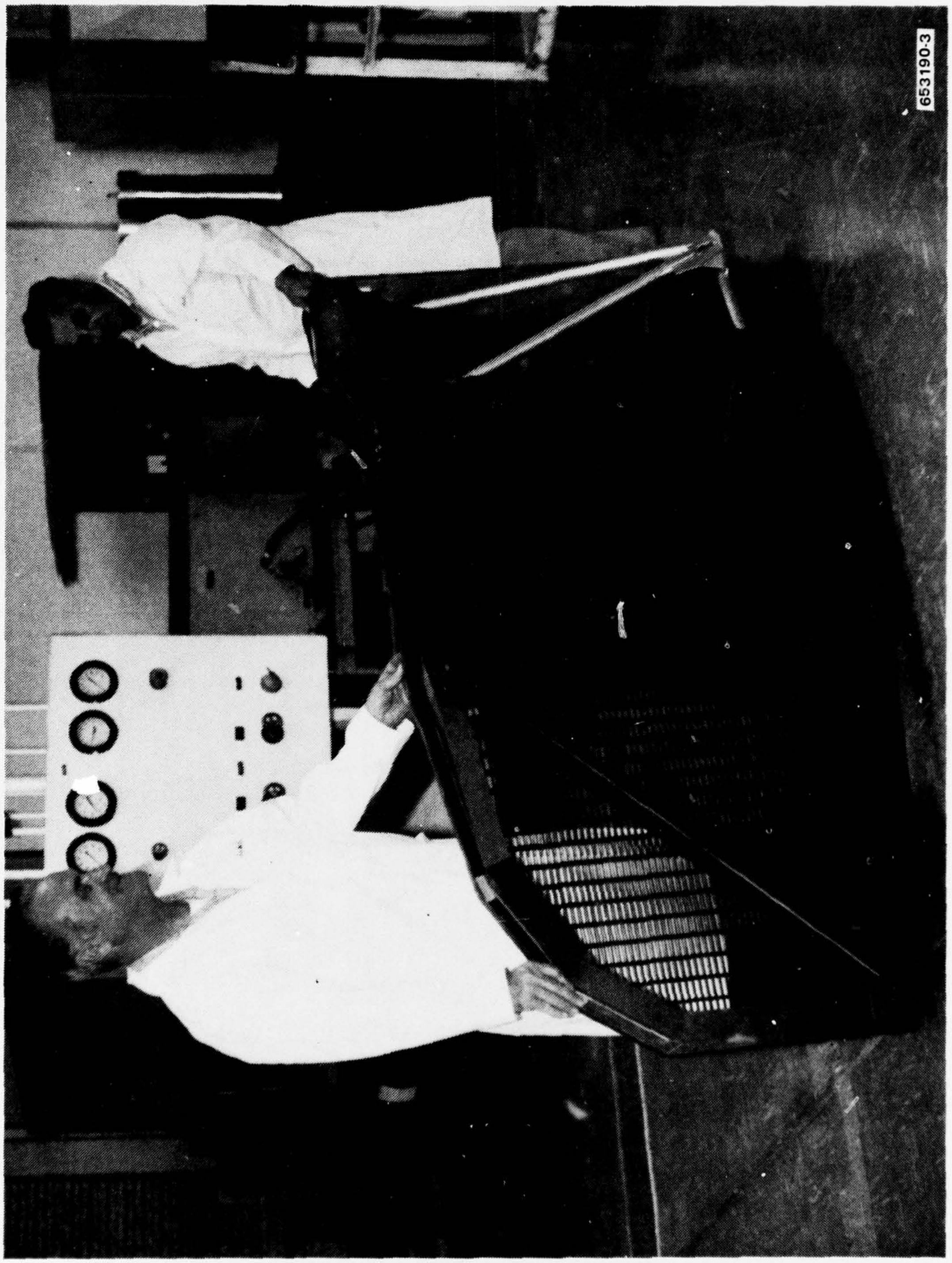

Figure 2. Graphite/epoxy SPS-10 reflector - side view

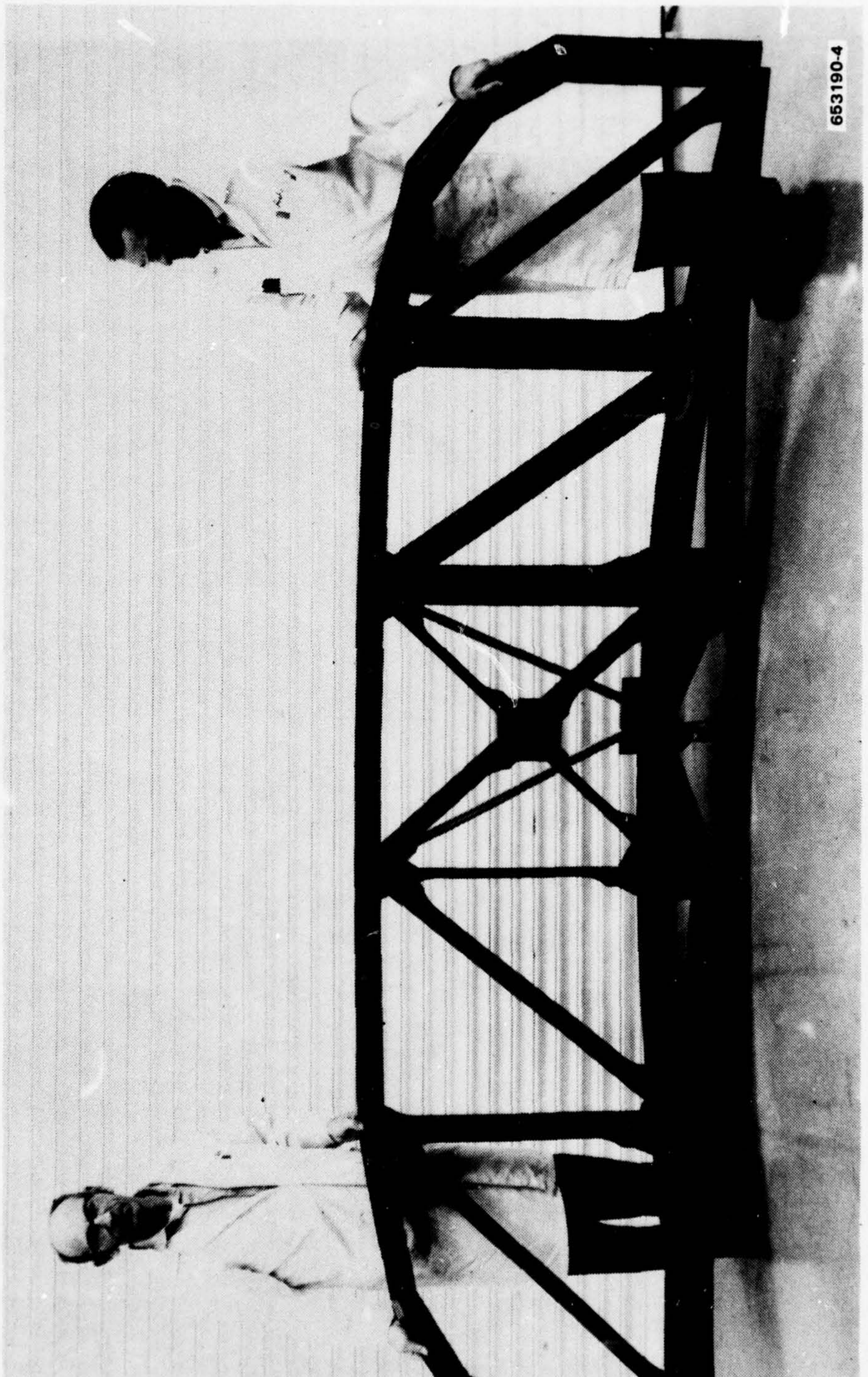

Figure 3. Graphite/epoxy SPS-10 support structure - front view

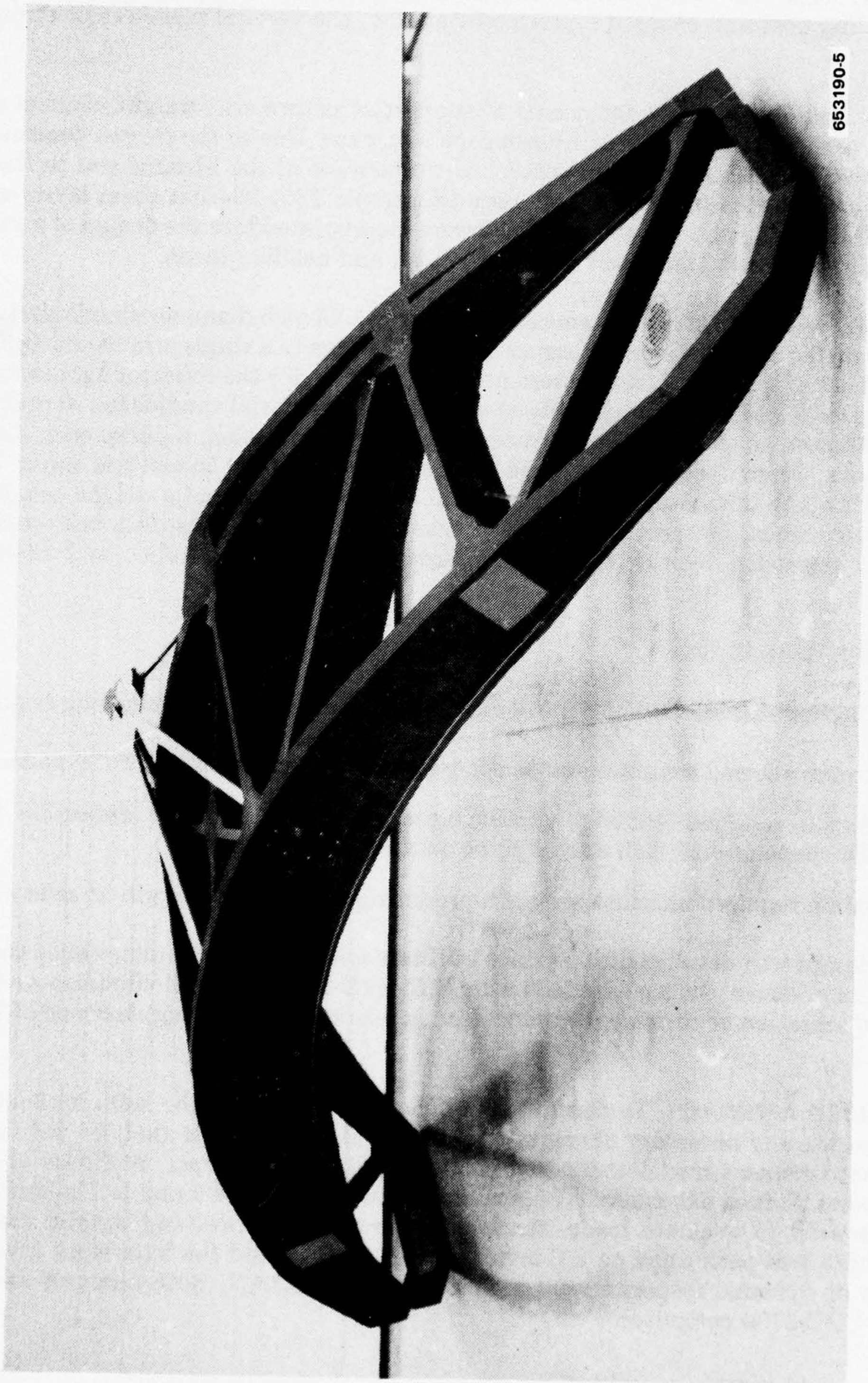

Figure 4. Graphite/epoxy SPS-10 support structure - side view

reflector peripheral members have varying cross-section geometries that were most easily accommodated by using secondarily bonded I-beam sections fabricated from pseudoisotropic 10-ply (0.050 inch) and 14-ply (0.070 inch) flat layup T300/934 for the webs and caps. This reduced tooling cost and ensured a precise fit against the vertical members of the reflective grid.

The vertical and diagonal interior beams of support structure are straight channel members that join at each end to the curved I-beam caps and webs. Due to the curved geometry of the reflector, the diagonal members only attached to the webs of the I-beams and to the vertical channels. Gusset plates fabricated from pseudoisotropic T300/934 flat sheet layup and shear blocks cut from G10 glass/epoxy sheet stock were incorporated into the design of each joint to ensure rigidity and safe load paths for shear, axial, and bending loads.

2.1.1.3 Strut System. The strut system consists of four 1.25-inch diameter aluminum tubes that converge from four interior support structure joint fittings to a single arm mount fitting aft of the support structure. This strut system provides support for the reflector against tipping or overturning loads. After studying various strut system material candidates, aluminum alloy 6061 was selected as the best choice from the point of fabrication, tooling, cost, and weight considerations. Graphite/epoxy tubes and fittings were too costly to tool and layup. Titanium was too difficult to fabricate and stainless steel imposed too high of a weight penalty on the total reflector. Since the strut system was coated for corrosion resistance and would not be structurally degraded by the corrosive environment, aluminum tubes and fittings were selected.

2.2 STRUCTURAL ANALYSIS

2.2.1 DESIGN REQUIREMENTS. The SPS-10 antenna was designed to the following requirements:

a. A maximum allowed weight equal to the weight of the metal reflector (78 pounds).

b. A minimum required stiffness producing a maximum dynamic deflection from the parabolic shape of 0.25 inch at any point on the reflective grid.

c. A minimum required ultimate strength producing a minimum margin of safety of +1.0.

The final design was developed to produce stiffness and strength characteristics that satisfy the design requirements when exposed to the MIL-STD-167A (SHIPS) vibration environment. This forced vibration environment produced an acceleration in the neighborhood of 70g in the antenna.

2.2.2 ANALYSIS APPROACH. To permit cost-efficient evaluation of the reflector configuration and incorporate any necessary changes, the structural and dynamic analysis were conducted using a finite element model comprised of beam and plate elements. Stiffness of boundary elements were derived externally. The model is shown in Figures 5 and 6. The finite element model was used to evaluate loads, stresses, natural frequencies, and weight. Early static analysis work was performed on a Convair version of SAP and the later work involving the evaluation of dynamic response was performed on NASTRAN. Both analyses were run on Convair's CDC 6700 computer.

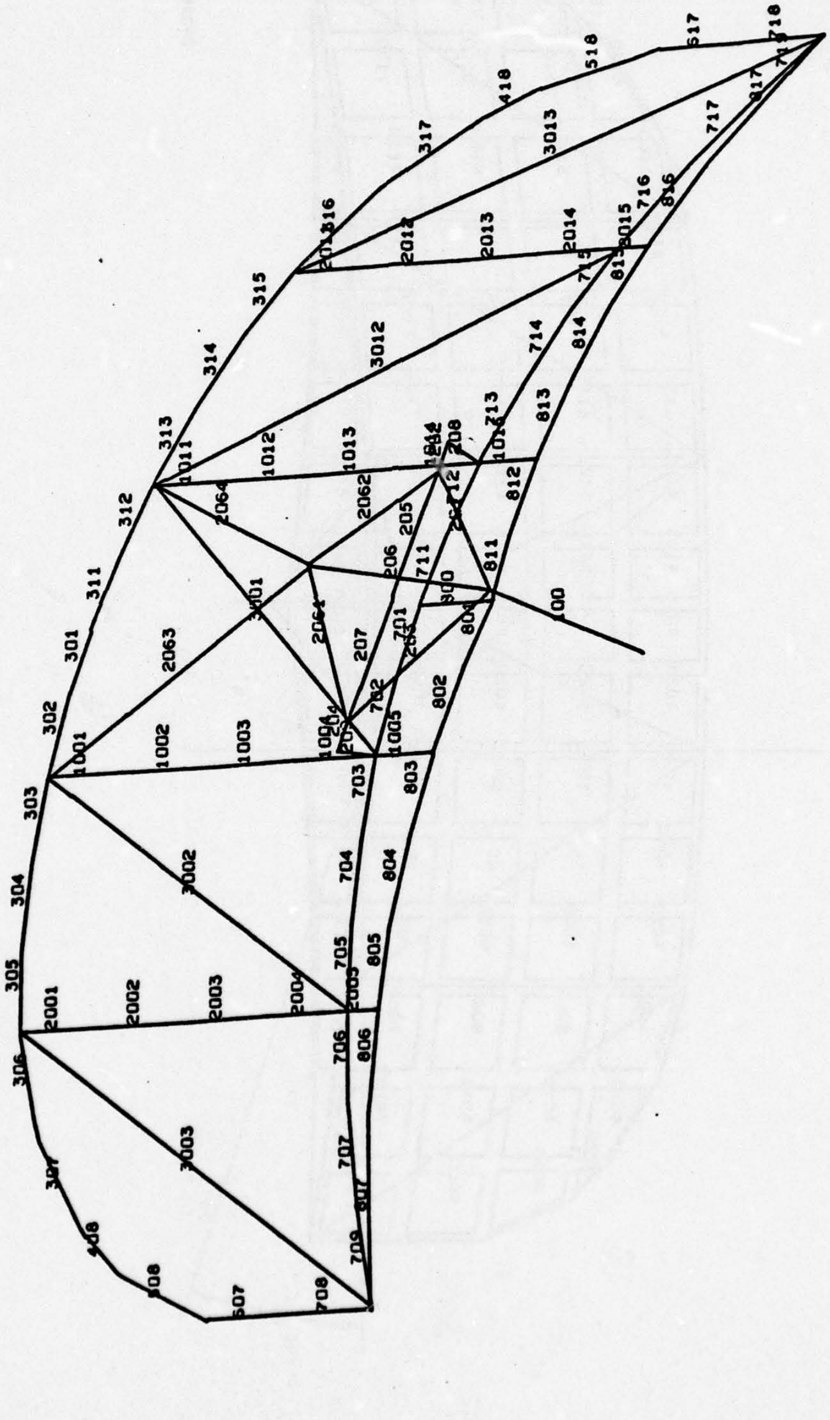

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Figure 5. Finite element model of the SPS-10 support structure strut system and arm mount

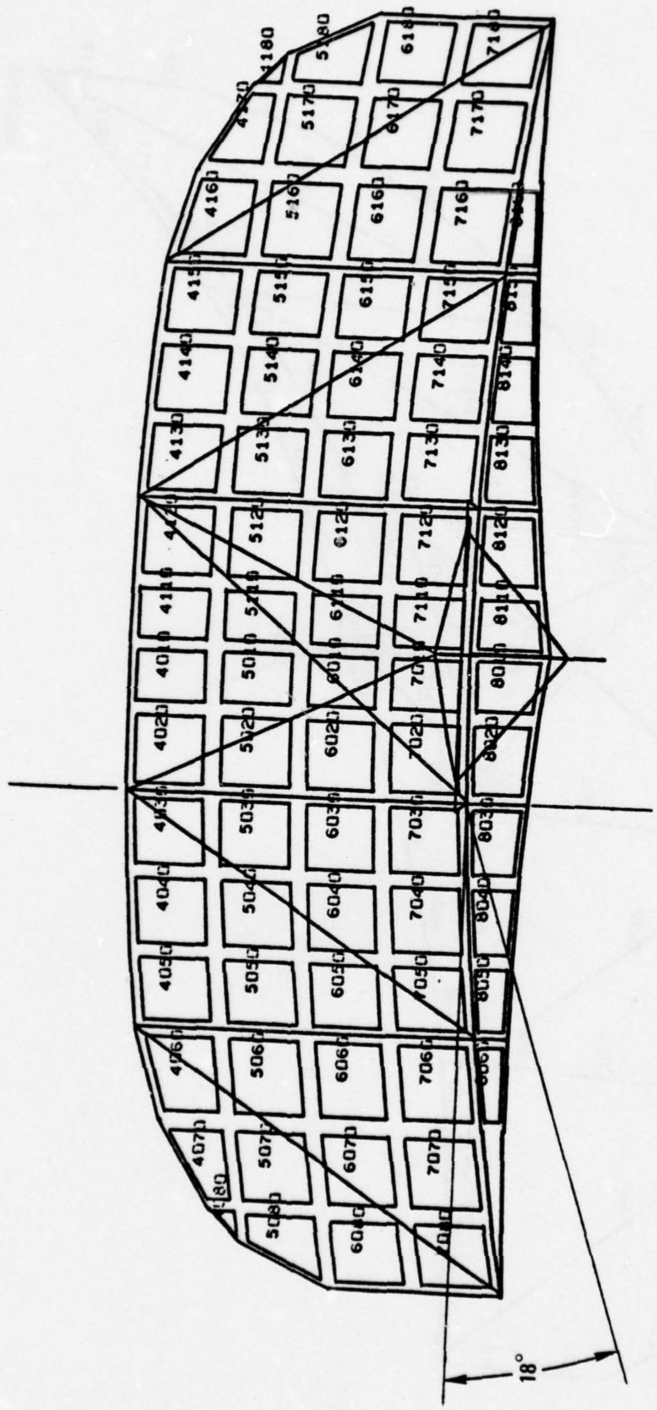


Figure 6. Finite element model of the SPS-10 reflective grid plate

Geometry of the math model fully evaluated the parabolic reflector mesh and support structure geometry, strut system, arm mount, and pedestal. The reflective mesh grid was modeled as triangular plate elements with a minimum stiffness. All structural elements for the support structure, strut system, arm mount, and pedestal consisted of bending members.

Material laminae orientations accounted for the orthotropic properties of the various composite laminates, i.e., support structure I-beam and channel sections (caps and webs), and the reflector mesh components. Table 1 shows the T300/934 graphite/epoxy material laminae and laminate design values.

TABLE 1. TYPICAL PROPERTIES OF T-300/934 GRAPHITE/EPOXY

Property	Tape 0°	Tape 0°/90°	Isotropic
Laminate Thickness (in.)	0.005	0.020	0.040
Cured Density (lb/in^3)	0.058	0.058	0.058
Strength (ksi)			
F_{tu}	200	120	71.7
F_{cu}	190	110	65.4
F_{su}	15	11	8
Modulus (msi)			
E_{11}	19.5	9.81	7.8
E_{22}	1.5	9.81	7.8
G_{12}	0.6	0.6	–
Poisson, ϑ_{12}	0.32	0.05	–

2.2.3 ANALYSIS RESULTS

2.2.3.1 Static Analysis. Since the design requirements made this reflector a stiffness-critical design, results from the static structural analysis show a minimum margin of safety of +1.0 in strength and positive margins of safety in buckling for all support structure and strut system members. These margins of safety are based on the reflector unit being subjected to a 70g load in any one of the three orthogonal directions. Margin of safety is defined as:

$$\text{M.S.} = \frac{\text{Ultimate Stress} - \text{Design Stress}}{\text{Design Stress}}$$

Most members sizings yield strengths well above these minimum margins of safety. Joint gusset plates and shear blocks were designed with much higher margins of safety, such as 3.0 minimum.

2.2.3.2 Dynamic Analysis. The dynamic analysis was conducted in two parts; analysis of peak load stresses due to; vibration loads according to MIL-STD-167A (SHIPS) Mechanical Vibration of Shipboard Equipment, and shock loads according to MIL-S-901C. Study of the vibration loading cases was conducted after the initial sizing of the antenna members had been performed. A peak ultimate load level of 70g (static) was derived and evaluated to be equivalent to the vibratory design requirement for the antenna in each orthogonal axis. Discussion of the static analysis results for the 70g load case was presented in 2.2.3.1.

The shock analysis was not conducted until after the vibration performance tests had been completed and had thus provided us with the dynamic characteristics of the antenna arm mount and pedestal necessary for our analytical model. This information was necessary since it was decided to perform the shock analysis on the entire antenna structural system (reflector, arm mount, pedestal). The input shock history used for the shock analysis model (see Figure 7) was the actual acceleration history monitored at the mounting base of a Naval antenna structure subjected to the MIL-S-901C shock test procedure. Similarly, this shock history was input at the SPS-10 pedestal base in the finite element model. Summaries of maximum nodal accelerations and maximum member response stresses due to the shock excitation are presented in Tables 2 and 3. Maximum response stresses due to shock excitation exceed the T300/934 graphite/epoxy pseudoisotropic layup strength and buckling stability allowables for the center bay vertical and diagonal members (refer to member numbers 701 and 1001 in Figure 5). Due to schedule and budget considerations, it was not feasible to take appropriate actions to redesign, analyze, and refabricate those members and retest the reflector to meet the qualification standards of MIL-S-901C. We feel that this is dynamic analysis model has developed a data base applicable to the redesign and reanalysis of a production SPS-10 unit or other type of Naval reflector.

TABLE 2. SUMMARY OF MAXIMUM ACCELERATION DUE TO SHOCK EXCITATION

Excitation Direction	Model Node Point*	Maximum Peak Acceleration (g) X-Direction	Y-Direction	Z-Direction
X	206	101	8	107
	305	124	74	101
	708	152	141	165
	805	123	96	75
Y	206	1	286	2
	305	80	130	156
	708	97	231	271
	805	115	182	131
Z	206	81	3	256
	305	44	14	262
	708	113	55	262
	805	68	17	251

*See Figure 5.

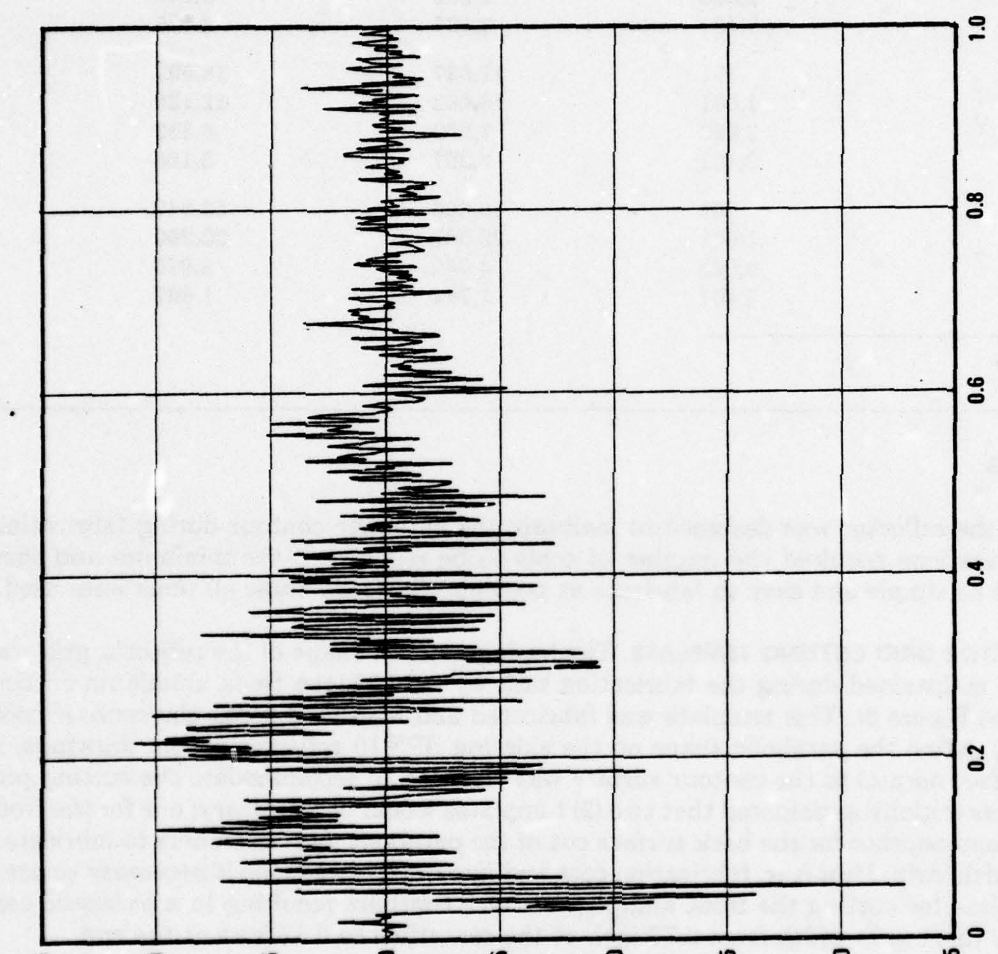


Figure 7. Input shock history

TABLE 3. SUMMARY OF MAXIMUM RESPONSE STRESS DUE TO SHOCK EXCITATION

Excitation Direction	Model Element No.*	Maximum Peak Stress (psi) Tension	Compression
X	701	17,372	21,805
	1,001	8,904	7,388
	2,063	2,359	3,240
	3,401	2,295	2,175
Y	701	17,527	16,591
	1,001	16,262	12,125
	2,063	7,999	6,332
	3,401	4,297	5,186
Z	701	49,606	53,842
	1,001	22,561	20,960
	2,063	4,040	3,875
	3,401	1,744	1,637

*See Figure 5.

2.3 TOOLING

Tooling for the reflector was designed to maintain the parabolic contour during fabrication. Cost considerations required the number of tools to be reduced to the minimum and their design to be as simple and easy to fabricate as possible. Basically three (3) tools were used.

2.3.1 REFLECTOR GRID CUTTING TEMPLATE. The basic parabolic shape of the reflector grid was defined and maintained during the fabrication task by a 0.190-inch thick aluminum cutting template (see Figure 8). This template was fabricated and inspected using the contour coordinates that define the parabolic shape on the existing SPS-10 reflector design drawings. A 0.75-inch offset normal to the contour surface was required to accommodate the cutting procedure. It was initially anticipated that two (2) templates would be necessary; one for the front surface cut and another for the back surface cut of the parabolic mesh members to fabricate a constant width strip. However, fabrication cost and material waste made it necessary to use a single template for cutting the front and back surface contours resulting in a parabolic contoured strip varying in width from 0.77 inch at the centerline to 0.57 inch at the end.

2.3.2 FINAL ASSEMBLY TOOL. The parabolic surface assembly tool shown in Figure 9 was formed by sweeping a plaster contour between two male templates. The contour of these templates was made from the drawings representing the "current" SPS-10 configuration. This eliminated any irregularities or discrepancies that would have been encountered using an "existing" SPS-10 antenna contour. Locations of the final assembled reflective grid members and their outside perimeter were scribed on the plaster surface.

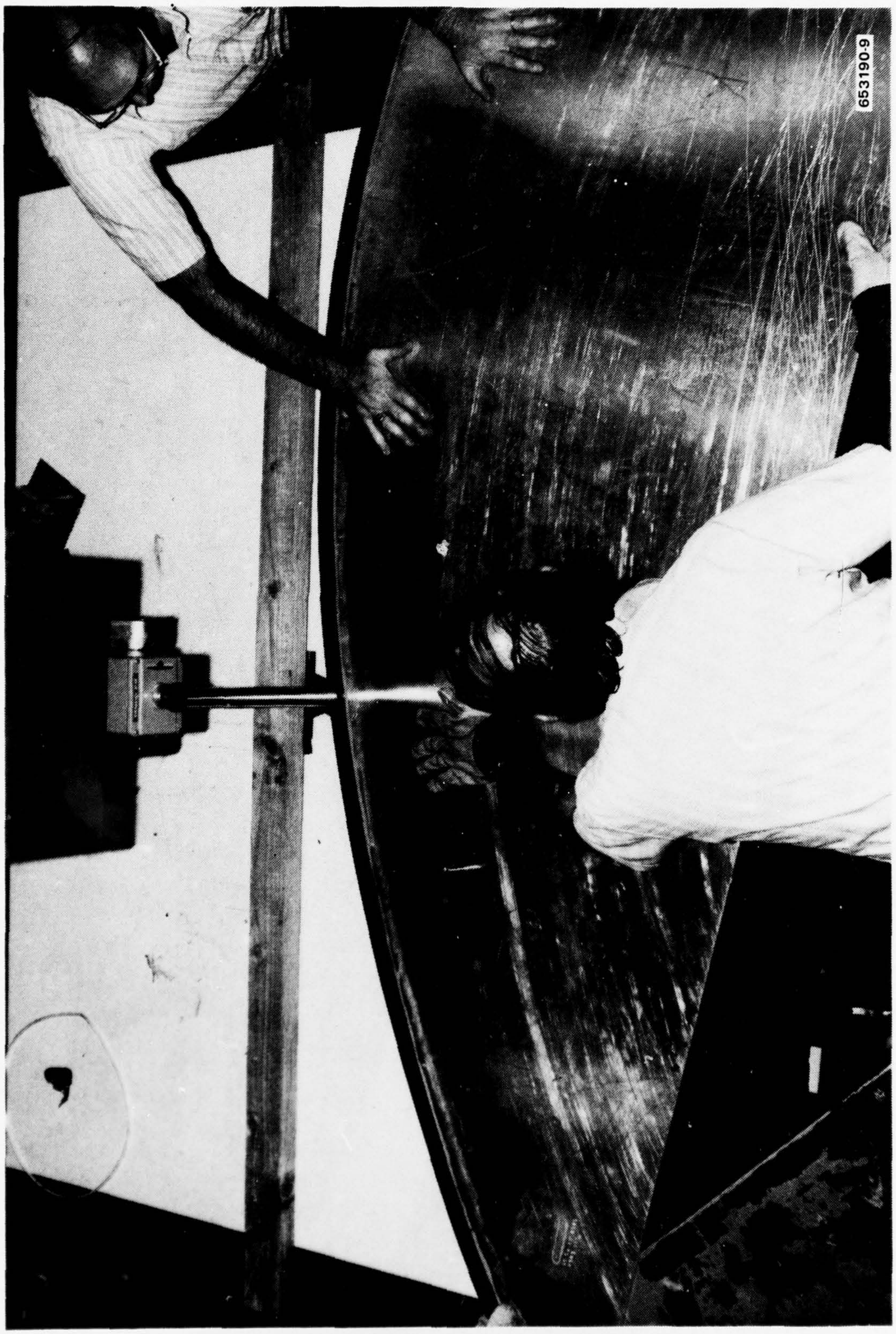


Figure 8. Reflector grid cutting template during fabrication

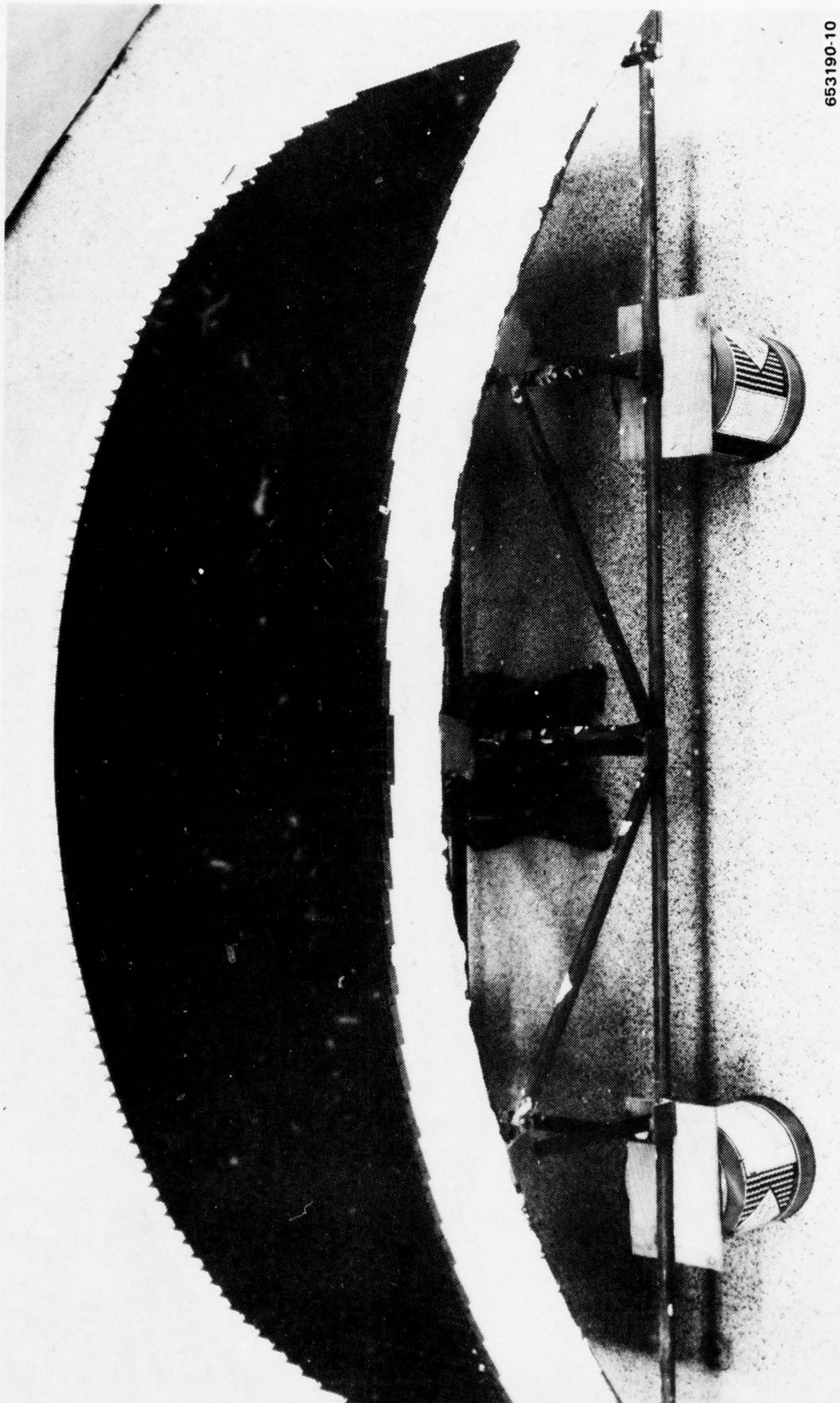


Figure 9. Reflector on parabolic surface assembly tool

2.3.3 CHANNEL SECTION LAYUP AIDS. Layup aids for some of the support structure members were fabricated as aluminum bend-on-break channel cross-sections (see Figure 10). This simplified tooling was the result of an early fabrication-to-cost decision made to eliminate a large portion of the hard tooling This also allowed longer channel sections to be layed-up and machined to the desired length and trim as necessary.

No additional tooling was necessary for the I-section members. Those sections were built-up from pieces cut out of a flat graphite/epoxy layup. The front edge contour of the I-beam web was defined using the reflector grid cutting template and the back edge contour was defined as a series of arcs and straight lines. The peripheral surface of the upper parabolic I-beam was not curved as in the present metal configuration, but instead, followed such curvature as straight-line segments to reduce tooling cost.

Additional assembly aids were developed and used as the need arose during the assembly phase, but these aids had a minimal effect on the tooling cost. All of this significantly lowered the tooling cost.

2.4 FABRICATION

The flat element adhesive bonding concept was used for fabricating the single prototype unit. In this approach, the required tooling consists only of a plaster master assembly tool for fabricating the grid-reflector, and a very simple layup mandrel/tool for each of the channel cross-section beam members. This approach was selected as a result of a study conducted of various methods for fabricating a graphite/epoxy SPS-10 grid reflector and support structure. Cost comparisons were made of each toward arriving at two final preferred methods: flat element adhesive bonding, and thermal pressure forming (TPF) using elastomeric tooling. Flat element adhesive bonding was shown to be lowest cost for fabricating from one to 20 units, while the TPF concept was more efficient and cost effective in fabricating larger numbers of units. These studies showed that tooling costs dictated the fabrication concept to be used.

2.4.1 REFLECTOR GRID. All composite parts of the grid were cut as flat elements from graphite/epoxy sheet stock. Due to the high cost in labor and material waste and the high degree of machining accuracy required, conventional machining techniques were deemed too costly for the parabolic members. Contoured grid members were fabricated using the water jet technique. Figures 8, 11, and 12 show various stages of the water jet cutting technique. This decision allowed elimination of much material waste, since a single contour cut defined the backside of one parabolic member and the front side of the next parabolic member cut. Also, the actual fabrication cost was significantly lowered by using the water jet technique. The template used to cut these members to the required parabolic curvature was described in 2.3.1. Vertical grid members were cut with a diamond-coated circular saw disc because they are straight. Slotting of the straight grid-reflector vertical slats was accomplished by stacking elements and sawing the required slots in each stack. This ensures perfect alignment and fit of each member.

The assembly tool was appropriately indexed for the location of each horizontal and vertical slot. The slotted elements were then placed in position on the back surface contour of the parabolic members on the assembly tool and bonded at each joint. Each joint was retained at

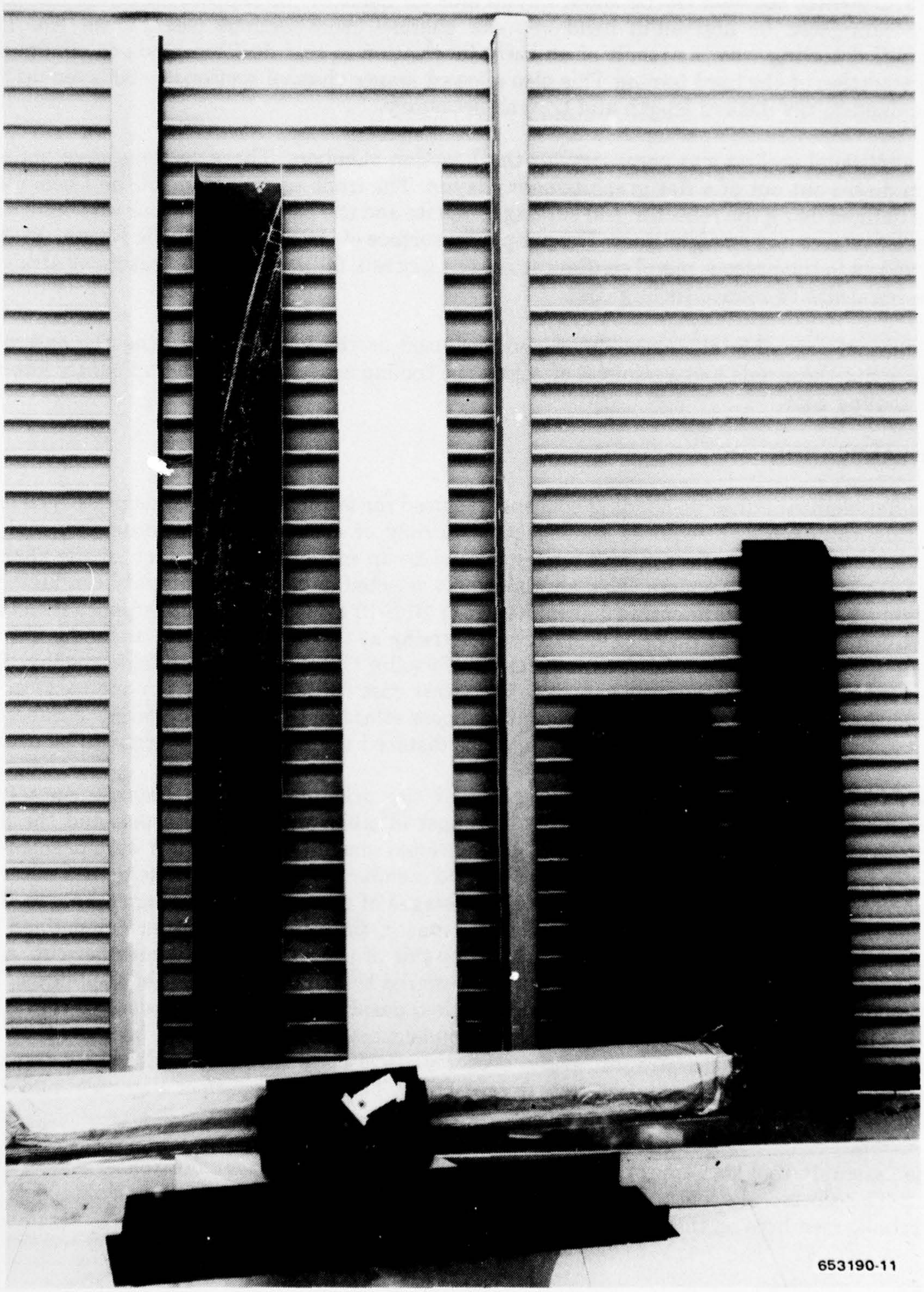


Figure 10. Channel section layup aids (left) and cured graphite/epoxy channel sections (right and foreground)

Figure 11. Water jet cutting technique for the reflective grid

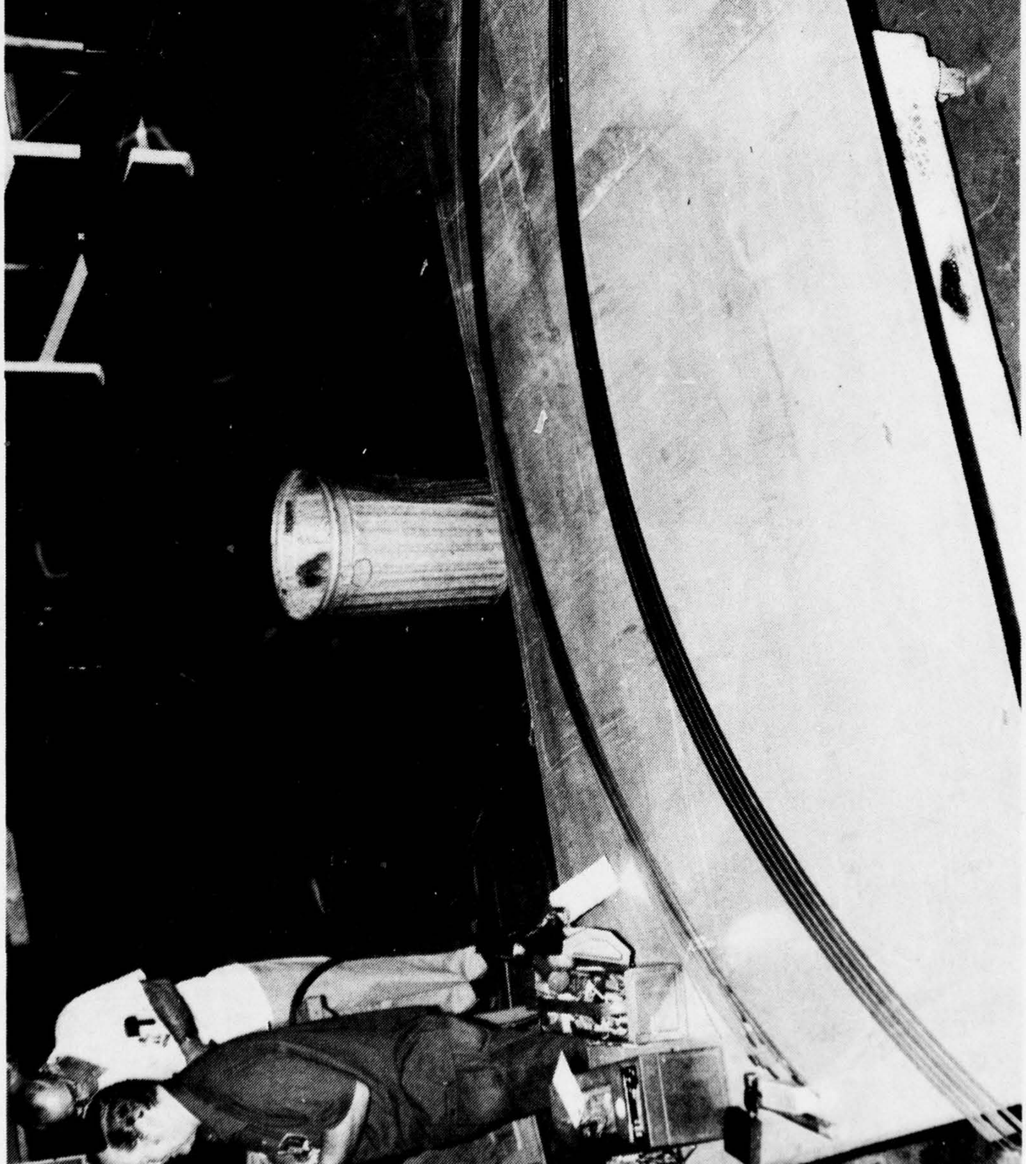


Figure 12. Fabricated parabolic reflective grid members

the correction position and orientation by a series of individual wooden "clothespins." These assembly aids were basically a wood block with a single slot for a snug fit over the grid member without scratching the slat surface. Hysol EA934 room-temperature-curing adhesive was applied at each egg-crate joint. Excess adhesive on the reflective face was manually wiped off. The part was then allowed to be set at room temperature for 24 hours to gain full strength.

2.4.2 SUPPORT STRUCTURE. The deep beam support structure was fabricated from I-beams and channel members. The built-up I-beams were fabricated using web and cap elements cut from flat pseudoisotropic graphite/epoxy sheet stock and Hysol EA934 room-temperature-curing adhesive. Assembly aid blocks were used during fabrication of the I-beams. Channel members were laid up in mandrels and oven cured under vacuum and temperature. Details such as bulkheads and drain holes were added and edge trimming was performed before final assembly.

The support structure was completely assembled on the back edges of the assembled reflective grid as it rested on the plaster assembly tool. This eliminated the cost of additional tooling and ensured a smooth fit between the reflective grid and the support structure. Final assembly of the support structure was completed in two phases. It was initially completely assembled with cleco fasteners and gusset plates at the joints to verify all trim details and make any changes necessary to maintain good workmanship (see Figure 13). The reflector was then disassembled and final assembled, attaching all T300/934 gusset plates and G10 glass/epoxy shear blocks and the strut system fittings (see Figures 3 and 4).

Strut system fittings were welded using 6061-T6 aluminum alloy stock and all tubes and fittings were anodized with a sulfuric acid anodic coating and a polysulfide sealant applied. The strut system was completely welded in place during final assembly, and the tubes and fittings were coated with one (1) coat of epoxy polyimide primer and two (2) coats of polyurethane top coat.

After completion of the two structural performance tests, wind and vibration, the entire reflector grid and structural support was coated with one (1) coat of epoxy polyimide primer and two (2) coats of polyurethane top coat for ultraviolet radiation protection.

2.5 QUALITY ASSURANCE

The quality assurance plan for the composite SPS-10 antenna reflector was implemented per contract requirements and brought to a successful completion with no changes. This quality assurance plan was developed to support this contract that required deliverable hardware, test reports, and analyses reports, all produced under research and development engineering direction. This plan was required by Convair Standard Practice SP G2-10 to provide definition of requirements and responsibilities of quality assurance support.

Quality assurance contributions to the program began with on-board design review and design approval. Considerations incorporated into the design included the clarification of assembly sequence noted, the identification of critical inspection areas, the creation of instructions for verification test specimens and test results, the relaxation of dimensional tolerances, which were not really required to be close, and the clarification of dimensioning methods.

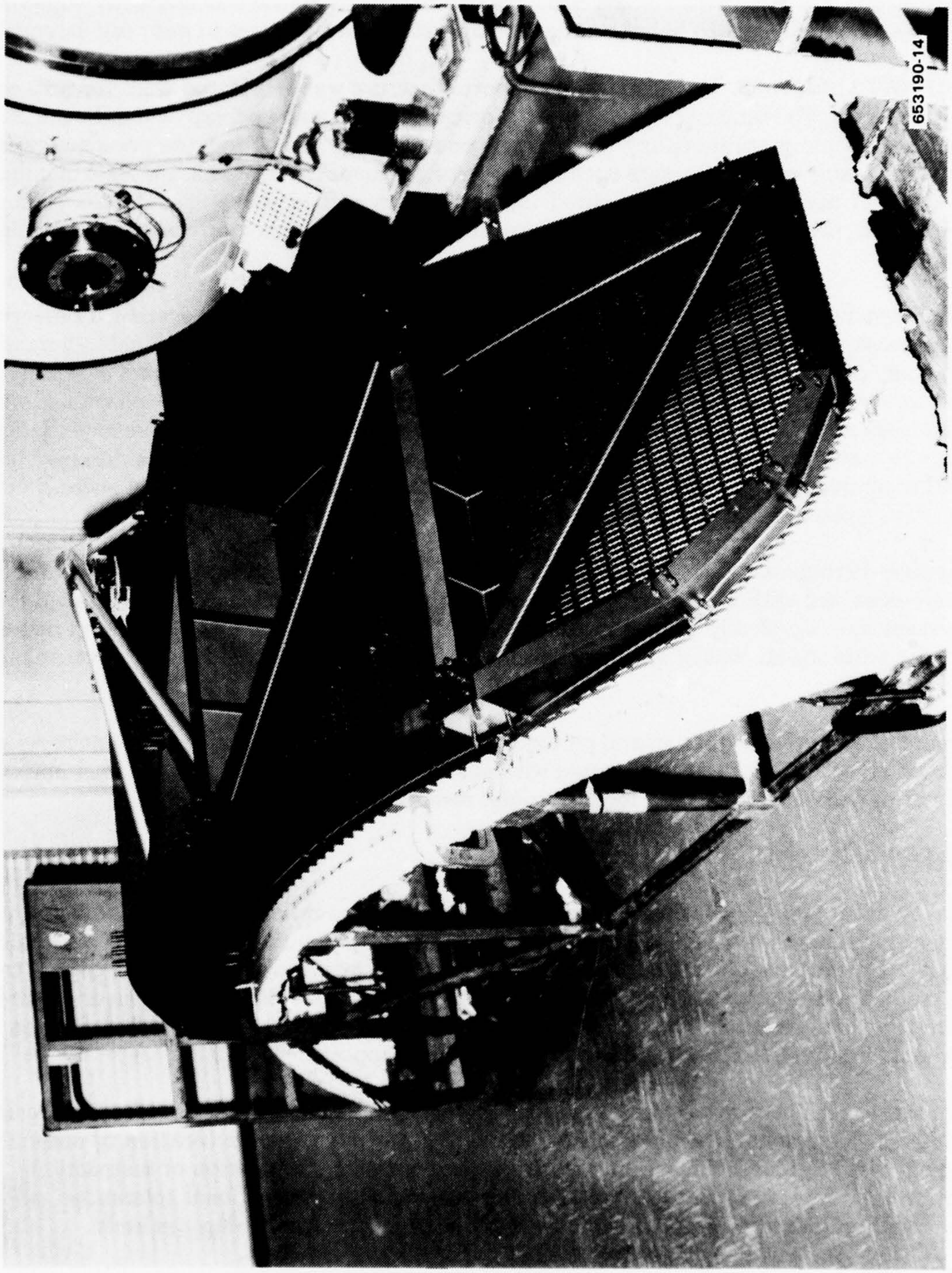


Figure 13. Initial assembly of composite SPS-10 reflector

All items were fabricated per Convair design drawings. Raw materials certifications of physical and chemical properties were maintained and are available upon request. Inspection during the reflector fabrication encompassed the following tasks:

a. The inspection of raw material at receipt.

b. The inspection at the detail and subassembly levels.

c. The final inspection of the SPS-10 radar reflector for visual defects and physical characteristics prior to delivery. Dimensions were recorded on a drawing furnished by the program manager, which in turn, is retained as his "as-built" record.

d. The inspection during packaging and preparation for shipment per QAM 8-1.

e. All discrepancies noted during inspections were documented and forwarded to the program manager for disposition. No formal corrective action program was necessary.

A certification of conformance to contracted design requirements is included in this final technical report. See Figure 14.

GENERAL DYNAMICS
Convair Division

Date: 26 September 1979

CERTIFICATION OF CONFORMANCE

Part Name:	Composite SPS-10 Reflector
Quantity:	One assembly
Part Number:	72C0952-B/N
Serial Number:	L15630
Article:	001
Customer:	Naval Sea Systems Command (NAVSEA)
Contract:	N00024-78-C-5332

General Dynamics Corporation, Convair Division, certifies that the Composite SPS-10 Reflector conforms to and has been manufactured in accordance with the requirements of Contract N00024-78-C-5332.

Certified: J.A. Nugent
J.A. Nugent
QA Program Administrator

Figure 14. Certification of conformance

SECTION 3

DOCUMENTATION

Through the duration of the program, technical progress was reported to NAVSEA by two types of Contract Data Requirements List (CDRL) documents. They are: Monthly Activity/Progress/Status Reports and Operational/Performance Test Reports.

The Transmission and Reflectance Test Report, documenting the comparison study of the transmissibility and reflectibility characteristics of a metal test grid and a graphite/epoxy test grid, was submitted and approved in April 1978. This report demonstrated the feasibility of T300/934 graphite/epoxy for radar reflector use.

A Structural and Electrical Test Plan Procedures Report, describing the proposed operational performance test plan for the composite reflector, was submitted and approved prior to the performance tests. All tests cited in our original proposal and requested in the contract were described in detail and performed.

The Structural and Electrical Test Results Report was submitted 27 July 1979. Description of the test and test results are discussed in Section 4.

SECTION 4

TESTS

The structural and electrical performance tests were conducted in fulfillment of CDRL Items 002, 003, and 004 for Contract N00024-78-C-5332. These tests were designed to provide sufficient data to ensure the structural integrity of the graphite epoxy reflector and to indicate its level of electrical performance. All tests were supervised by Gary Tremblay, General Dynamics Convair Program Manager, and a representative from Naval Ocean Sea Center (NOSC), Mr. Jerry Boynes, Don Chappelle, and/or Harry Valasck. The tests were conducted in the following order: 1) natural frequency test, 2) wind tunnel operational test, and 3) elecrical test. A complete description of all performance test procedures and results are documented in the Structural and Electrical Performance Test Report.

4.1 NATURAL FREQUENCY TEST

The composite SPS-10 reflector (Part No. 72C0952) was subjected to a sequence of vibration tests on 5, 6, and 9 April 1979 in the General Dynamics Convair Division Structural Dynamics Laboratory in San Diego, California. The object of the tests was to determine the frequencies at which the antenna system has significant dynamic response and to evaluate the magnitude of those resonant frequency responses. The experimental approach consisted of low-level sinesweep tests in each of the orthogonal axes. The test data obtained from the sinesweep tests were used to obtain the following dynamic information:

- Resonant frequency
- Modal damping factor

Upon receipt, the test specimen was examined for configuration, workmanship, damage, and general acceptability. Sixteen accelerometers (Endevco Model 2200 Series) were mounted on the antenna system in the positions shown in Figure 15. The accelerometers were positioned in the three orthogonal directions as determined by the program manager prior to the test. Accelerometer outputs were monitored and recorded by use of real time direct write recorders.

The SPS-10 antenna system (pedestal and mounting arm) with the composite reflector was mounted on a qualified fixture in such a manner that the vibration input was applied along only one antenna axis during each test and at the pedestal mounting plane (see Figures 16 through 18). In an attempt to eliminate or dampen the slight "wobble" in the pedestal gear works, two light-gauge guidewires were attached from the mounting arm to the pedestal housing. Since the guidewires did not eliminate this wobble, which is also inherent to the operating mode of the antenna, it was decided to include an accelerometer at the rotating axis of the mounting arm. This arrangement of accelerometers at the base of the pedestal, the top of the pedestal, and at the base of the mounting arm was intended to provide enough data to evaluate the effect of the wobble in the pedestal gearwork.

Prior to the sinesweep test, a specified vibration level was input in the closed loop network of the vibration system. Accelerometer readings at the pedestal base were monitored to ensure

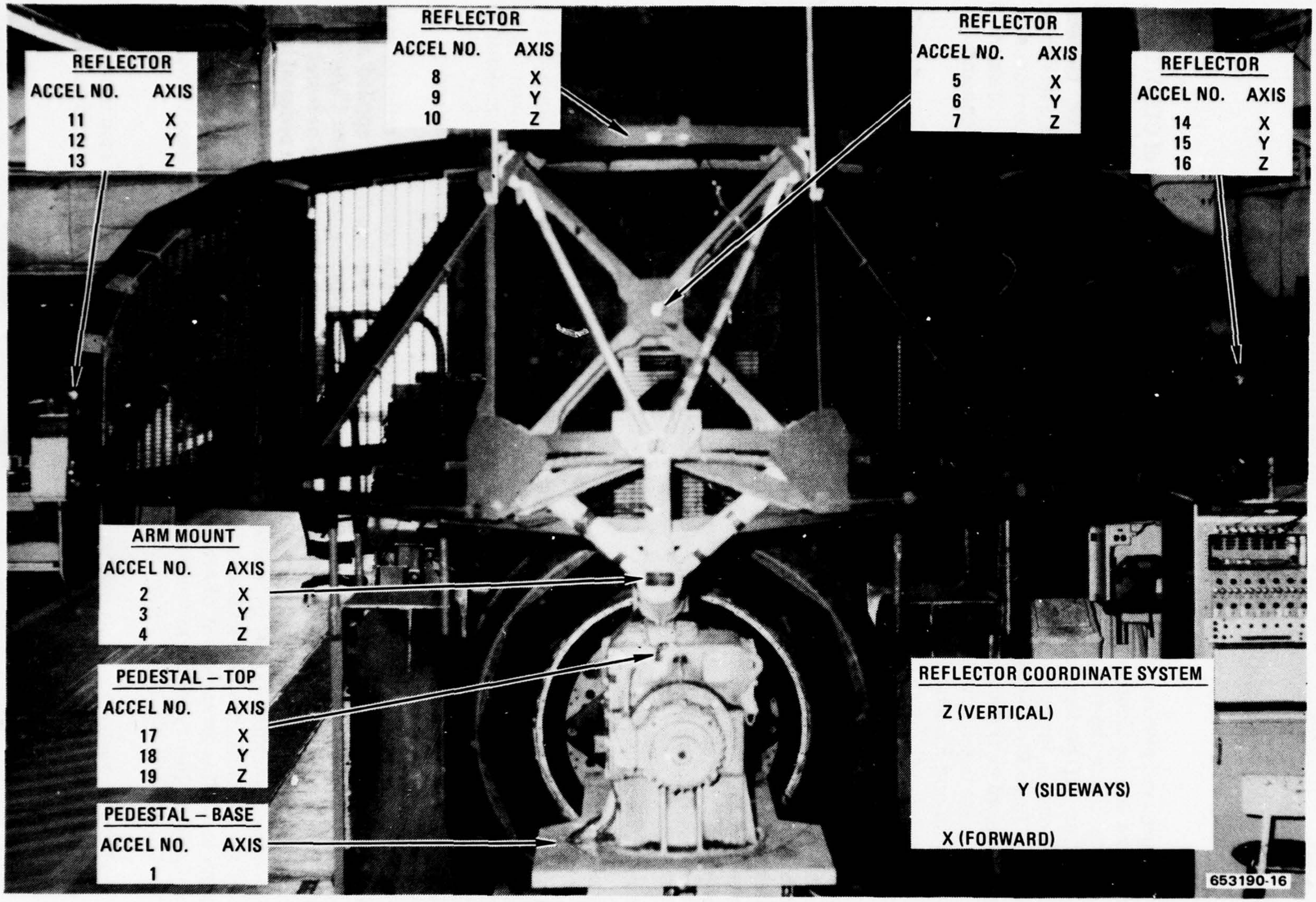


Figure 15. Vibration test accelerometer arrangement

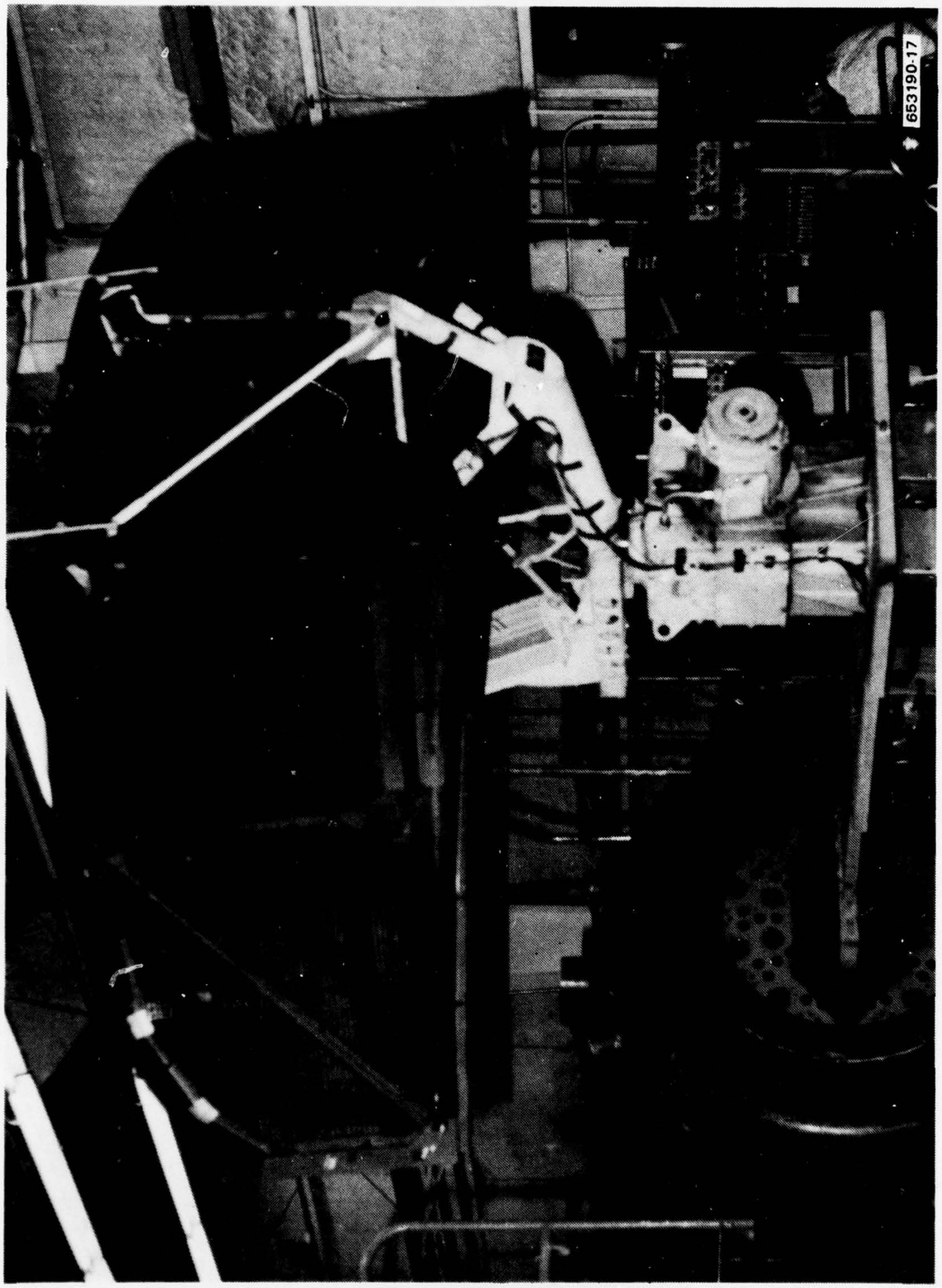


Figure 16. SPS-10 antenna system - vibration test (X-axis input) - back view

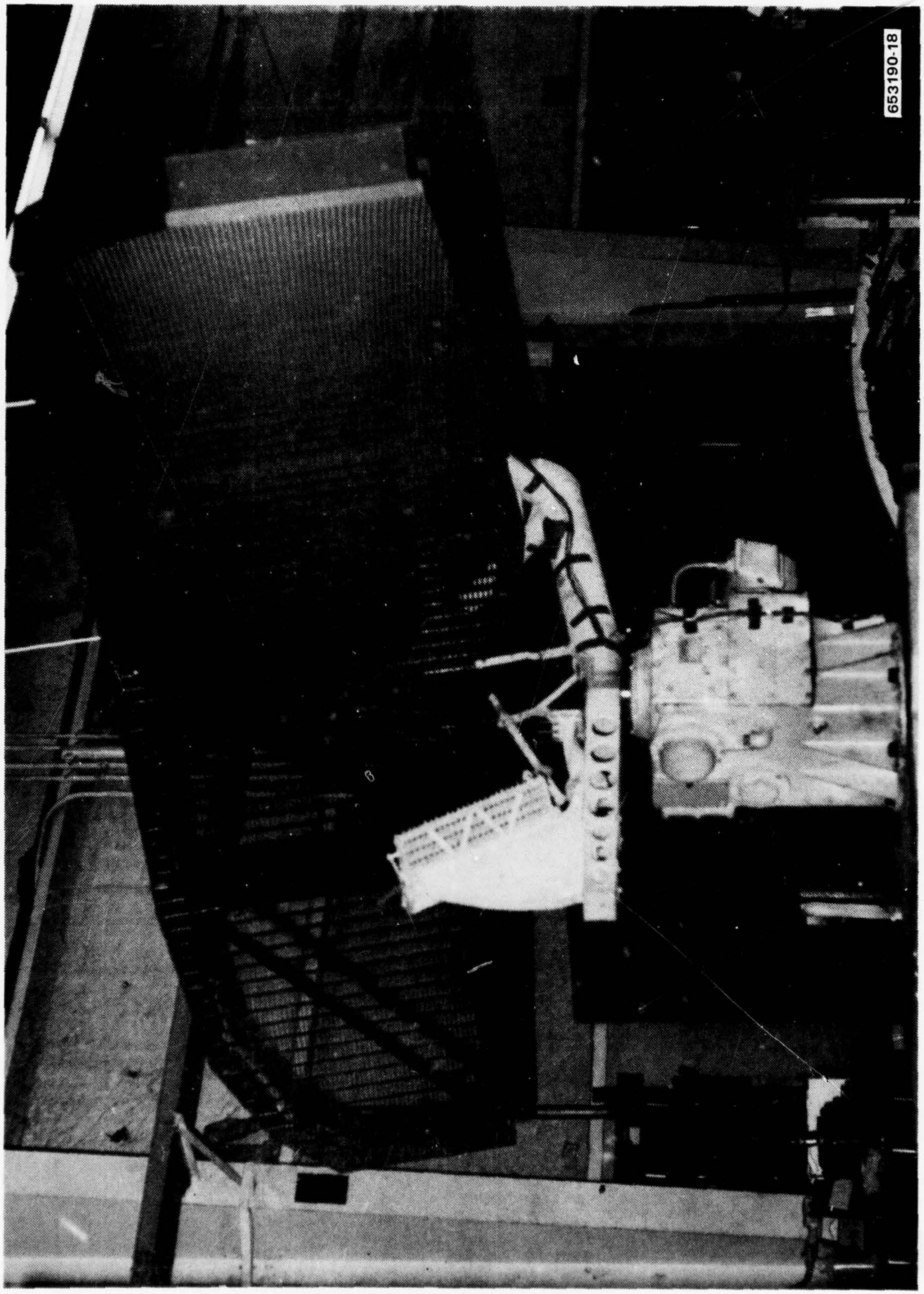


Figure 17. SPS-10 antenna system - vibration test (X-axis input) - front view

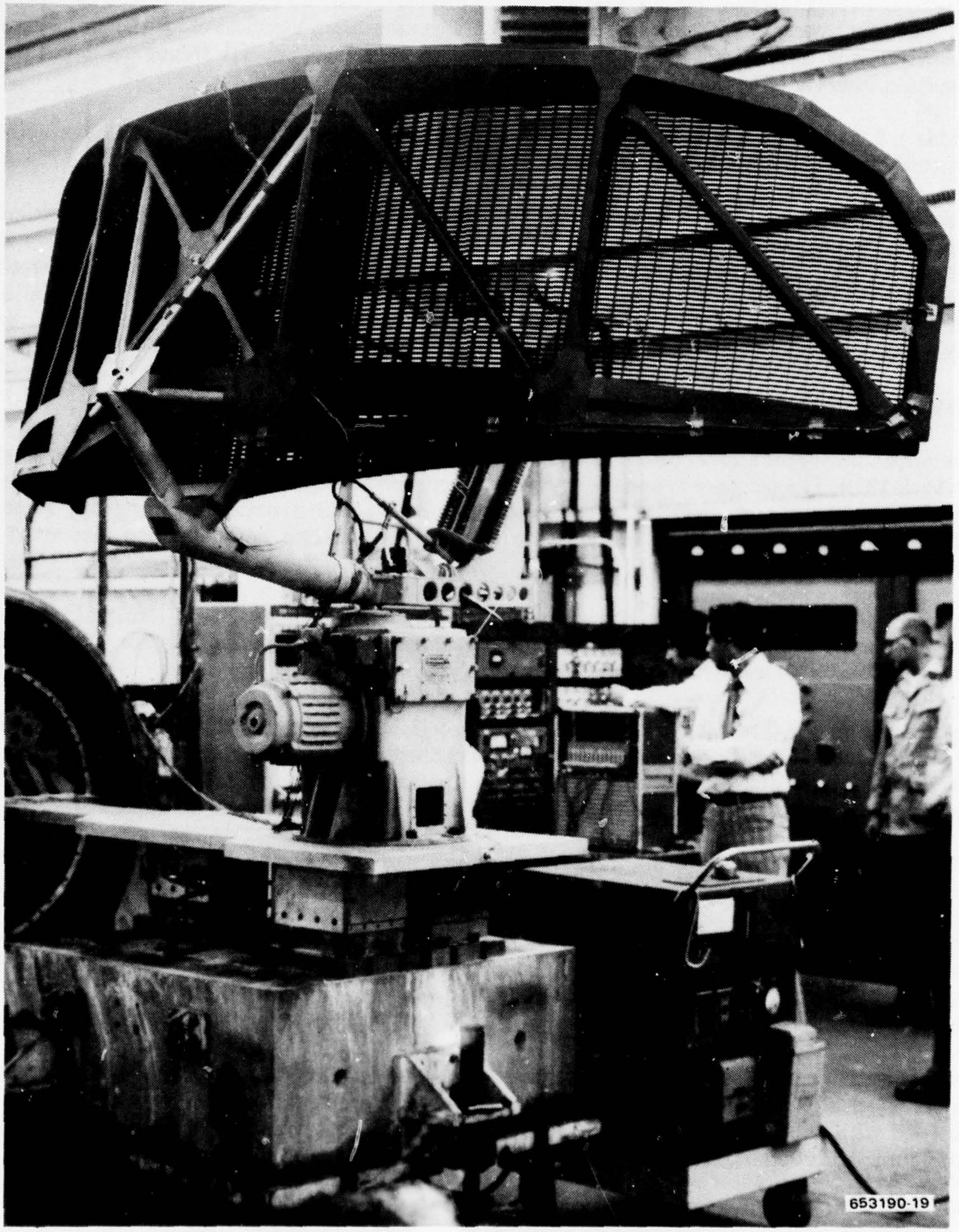


Figure 18. SPS-10 antenna system - vibration test (Y-axis input)

the correct input load level. It was decided to monitor all accelerometers and not allow any reflector response to exceed 10g. The sinusoidal vibration survey test was run according to MIL-STD-167A (SHIPS), Type I, Exploratory Vibration Test, up to 100 Hz. From 50 to 100 Hz, the input energy was held constant at 0.56g. The maximum input level for the single-axis sinesweep was approximately 0.85g rms. The step rate was one (1) frequency level per 15-second interval over the frequency range of 4 to 100 hz.

Tables 4, 5, and 6 summarize the measured frequencies that had significant dynamic response and their corresponding average damping.

After a thorough and complete analysis of the data summaries, we concluded that the critical resonant frequencies for the composite SPS-10 reflector and antenna system are as shown in Table 7. It was also concluded that the data collected to evaluate the effect of the inherent "wobble" in the pedestal gearwork on the average dampings, is inconclusive. It is characteristic of the pedestal/arm mount/reflector antenna system and should not be eliminated from the data.

4.2 WIND TUNNEL OPERATIONAL TEST

The wind tunnel operational tests were run in the General Dynamics low-speed wind tunnel on 10 April 1979. The purpose of the tests was to determine the effects of wind load on the rotational drive power requirements of the antenna and to confirm structural integrity. Windspeeds were varied from 10 to 100 knots with a desired one-half hour duration test at 100 knots.

The composite SPS-10 reflector, shown in Figures 19, 20, and 21, consists of four main parts. These are the antenna reflector, a spider mounting arm for mounting the reflector, a feedhorn assembly, and a pedestal-motor gearbox assembly.

Installation in the 8-foot by 12-foot tunnel test section was accomplished by attaching the antenna pedestal directly to the tunnel floor. The centerline of antenna rotation was located on the tunnel longitudinal centerline 1.94 inches upstream of the lateral centerline. Overall antenna dimensions were: height 74 inches, width 129 inches, and depth 62 inches.

All data taken were recorded manually from an airspeed indicator system and a drive power indicating system. The airspeed was converted from the equivalent dynamic pressure by recording the bellmouth pressure referenced to the ambient pressure. The tunnel airspeed was set to the proper value from a voltmeter and a strain gage transducer driven by the bellmouth pressure. Antenna rotation rate was monitored by visual observation. Input power measurements of voltage, amperage, and kilowatts were made from a Westinghouse, Type TA, multiphase industrial analyzer.

Test procedure consisted of first establishing an antenna rotation rate at the proper value with tunnel wind off. Rotation was in a clockwise direction viewed from above. All data were recorded with wind off, and then with wind on in 10-knot intervals to 100 knots or antenna maximum. At 100 knots, the composite SPS-10 reflector was run continuously for 10 minutes before the pedestal motor stalled and the test was shut down. Then the reflector was run continuously for 18 minutes before the pedestal motor stalled again and the test was shut down. Inspection of the pedestal motor operating characteristics without the wind load and review of

TABLE 4. SUMMARY OF MEASURED RESONANT FREQUENCIES AND DYNAMIC MAGNIFICANT FACTOR (X-AXIS VIBRATION MODE)

Input Freq Hz	Input Load (x) g	Response Load (g) Accelerometer No. 5 (x)	7 (z)	8 (x)	11 (x)	12 (y)	14 (x)	15 (y)	Average* Damping Max.	Total
7	0.032	0.10	0.07	0.12	0.50	0.10	0.50	0.05	0.056	0.078
10	0.060	0.32	0.18	0.36	0.40	0.14	0.40	0.14	0.111	0.108
13	0.12	1.3	1.0	1.8	1.2	0.16	1.2	0.11	0.090	0.062
16	0.20	0.50	0.50	1.0	0.85	0.32	0.80	0.14	0.190	0.170
25	0.60	0.32	0.50	1.0	2.4	0.95	2.4	0.40	0.195	0.263
33	0.90	2.0	2.0	3.2	5.2	3.2	8.5	1.8	0.096	0.135
43	0.40	0.36	1.2	0.32	1.0	0.60	1.2	0.40	0.250	0.276
53	0.90	1.0	1.1	1.0	2.0	0.60	1.9	0.37	0.370	0.395
56	0.56	0.65	2.0	1.1	3.4	0.90	2.4	0.54	0.155	0.178
60	0.56	2.5	2.5	2.5	4.5	1.6	4.0	0.95	0.101	0.106
77	0.25	0.50	1.0	1.1	5.0	2.0	5.0	0.90	0.039	0.056
84	0.25	2.2	0.90	2.0	9.0	3.8	9.0	1.0	0.022	0.031

*Maximum average damping is algebraic average for Nos. 11, 12, 14, and 15.
Total average damping is algebraic average for Nos. 5, 7, 8, 11, 12, 14, and 15.

TABLE 5. SUMMARY OF MEASURED RESONANT FREQUENCIES AND DYNAMIC MAGNIFICANT FACTOR (Y-AXIS VIBRATION MODE)

Input Freq Hz	Input Load (y) g	Response Load (g) Accelerometer No. 6 (y)	8 (x)	9 (y)	10 (z)	11 (x)	12 (y)	13 (z)	14 (x)	15 (y)	16 (z)	Average* Damping Max.	Total
9	0.04	0.75	0.05	0.32	0.14	0.35	0.40	0.50	0.40	0.04	0.40	0.056	0.059
28	0.55	1.6	0.51	0.50	0.85	4.8	3.9	4.9	4.5	3.0	3.5	0.067	0.098
31	0.20	2.1	0.40	0.50	1.2	3.7	4.2	6.5	4.0	3.4	5.0	0.022	0.032
34	0.25	0.40	1.5	0.12	0.95	1.0	1.3	2.8	1.4	1.0	3.2	0.070	0.091
43	0.40	0.40	0.35	0.25	0.90	1.4	1.0	1.7	0.98	0.70	0.28	0.198	0.251
56	0.56	0.16	0.20	0.16	0.60	1.4	0.60	0.38	1.4	0.32	0.32	0.380	0.505
64	0.56	0.40	1.3	0.40	1.6	1.2	0.85	2.4	0.70	0.60	1.6	0.229	0.253
78	0.27	0.21	2.2	0.33	2.5	10.0	4.0	3.2	14.0	2.5	2.3	0.023	0.024

*Maximum average damping is algebraic average for Nos. 11 through 16.
Total average damping is algebraic average for Nos. 6, and 8 through 16.

TABLE 6. SUMMARY OF MEASURED RESONANT FREQUENCIES AND DYNAMIC MAGNIFICANT FACTOR (Z-AXIS VIBRATION MODE)

Input Freq Hz	Input Load (z) g	Response Load (g) Accelerometer No. 5 (x)	7 (z)	8 (x)	10 (z)	11 (x)	12 (y)	13 (z)	14 (x)	15 (y)	16 (z)	Average* Damping Max.	Total
28	0.56	1.5	1.5	1.5	14.0	4.0	2.7	0.40	3.2	1.4	2.8	0.065	0.085
33	0.45	3.5	2.6	5.0	13.0	5.5	2.5	9.0	4.5	2.4	6.8	0.031	0.041
70	0.60	2.5	1.2	3.2	10.0	4.0	2.4	5.5	3.4	2.0	3.7	0.058	0.077
80	0.28	1.2	1.2	1.6	2.5	9.5	4.5	3.0	6.0	2.0	1.8	0.034	0.042

*Maximum average damping is algebraic average for Nos. 8, 10, 11, 13, 14, and 16.
Total average damping is algebraic average for Nos. 5, 7, 8, and 10 through 16.

TABLE 7. CRITICAL RESONANT FREQUENCIES OF COMPOSITE SPS-10 ANTENNA

Mode	Frequency (Hz)	Direction	Description
1	6-7	Θ_Z	Torsional Z-Azis
2	9-10	Θ_X	Torsional X-Axis
3	13	Θ_Y	Torsional Y-Axis
4	15-16	X	Translation X-Axis
5	25	Θ_Z	Torsional Z-Azis
6, 7, 8	33	X, Y, Z	System Resonance
	33		Complex resonance — more than one axis translation or rotation simultaneously

the pedestal operation manual indicated that the pedestal motor required additional oil in the gearbox. Oil was added to the gearbox to the level specified in the operation manual. The reflector was then run continuously for 30 minutes at 80 knots since it was necessary to complete a full duration test in the wind tunnel and delays had left us with time for one full duration run. At the completion of the 80-knot duration test, the wind was increased to 100 knots for four minutes at the request of Mr. Harry Valesek, NOSC respresentative. This additional step was to verify that there is no increase in the maximum input power amperage, with respect to time, at the higher wind load. Plots of input current and input power versus airspeed are shown in Figures 22 and 23. It should be noted that the existing SPS-10 mesh antenna data plotted in Figures 22 and 23 are from a prior wind tunnel study using a different SPS-10 pedestal mount.

The composite SPS-10 reflector wind tunnel test program was abbreviated and modified as discussed previously. During the 80- and 100-knot tests, the maximum input power amperage remained constant throughout the duration tests. No dynamic instabilities or structural failures were evident.

Drive power requirements for the antenna rotation system exhibited large fluctuations with azimuth as wind speed was increased beyond 35 to 40 knots. The range of these fluctuations was visually monitored and the maximum values were recroded for inclusion in this report. The rate of pedestal rotation remained constant throughout the complete 80- to 100-knot duration tests.

4.3 ELECTRICAL TESTS

4.3.1 GRATING TEST. Early in the SPS-10 program, a test program was conducted to compare the transmission and reflection characteristics of the proposed graphite/epoxy reflector grid

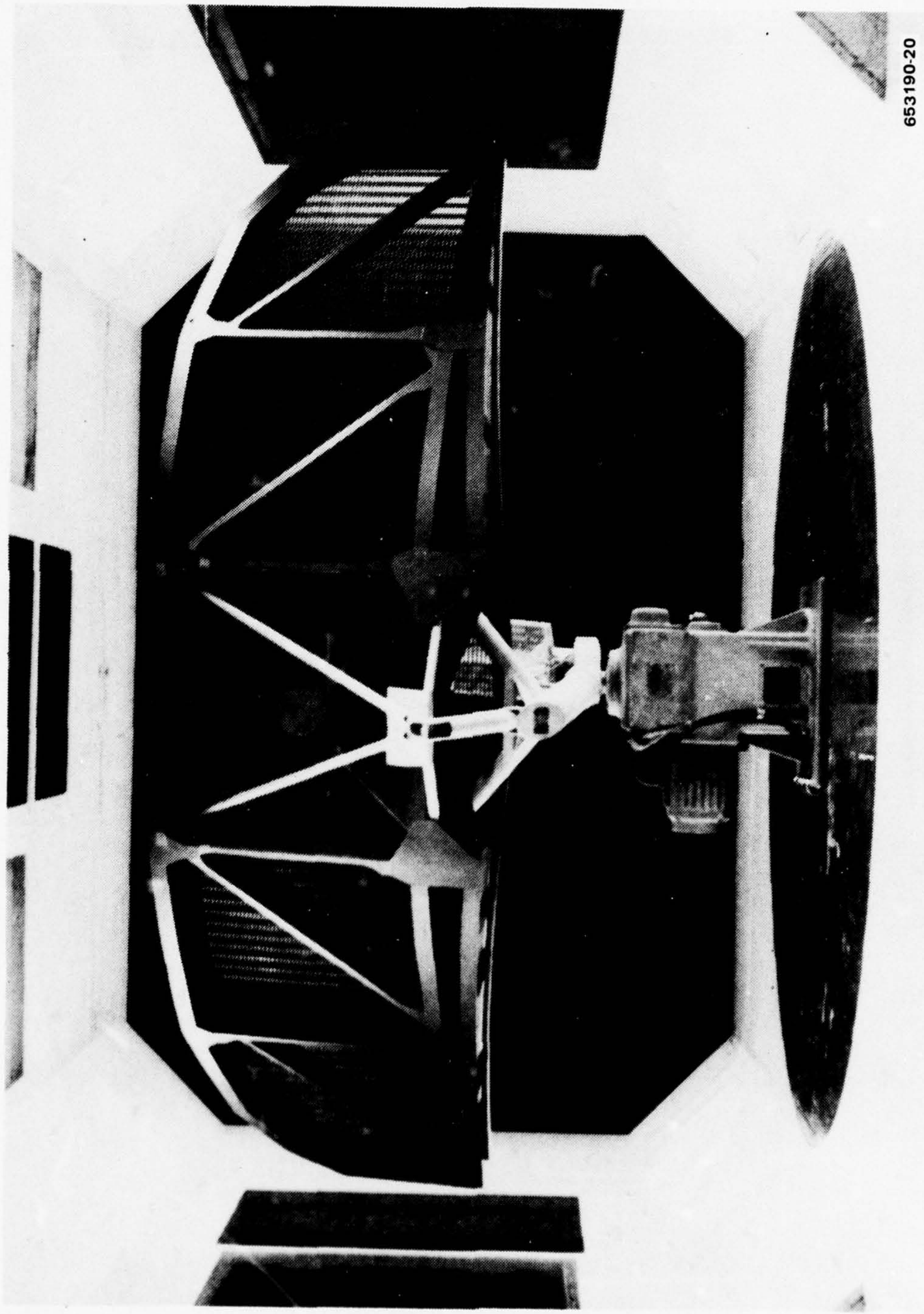


Figure 19. Composite SPS-10 reflector in low-speed wind tunnel - back view

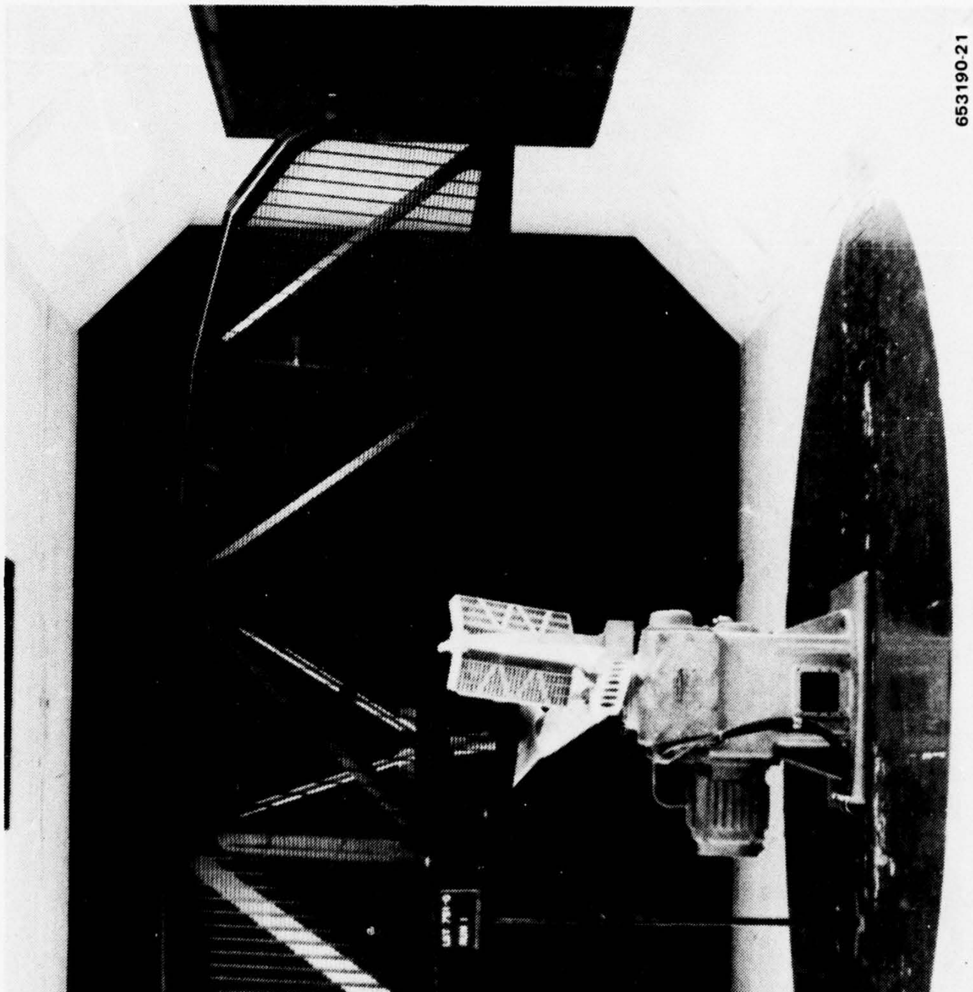


Figure 20. Composite SPS-10 reflector in low-speed wind tunnel - front view

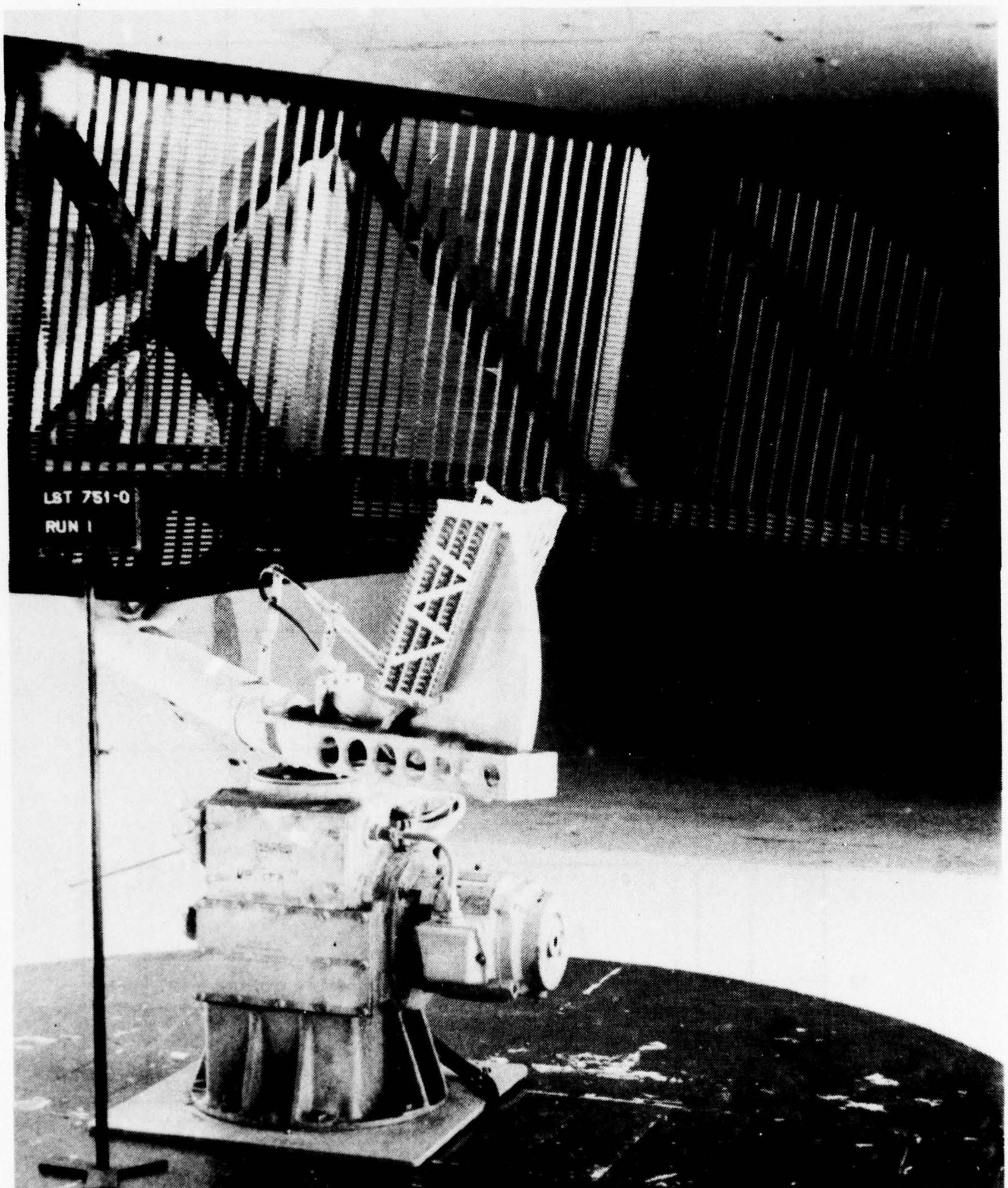


Figure 21. Composite SPS-10 reflector in low-speed wind tunnel - closeup view

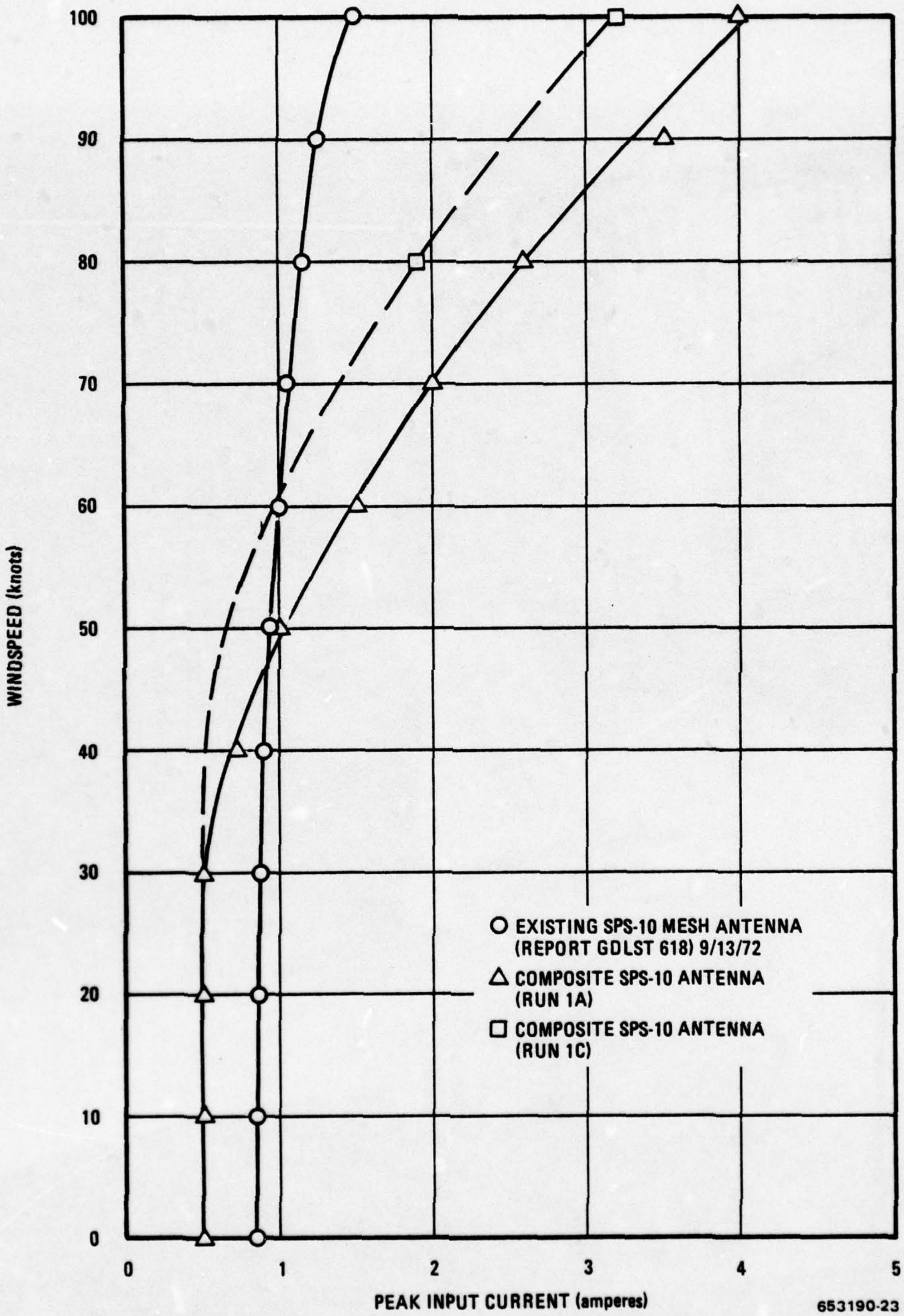


Figure 22. Peak input current versus airspeed plot

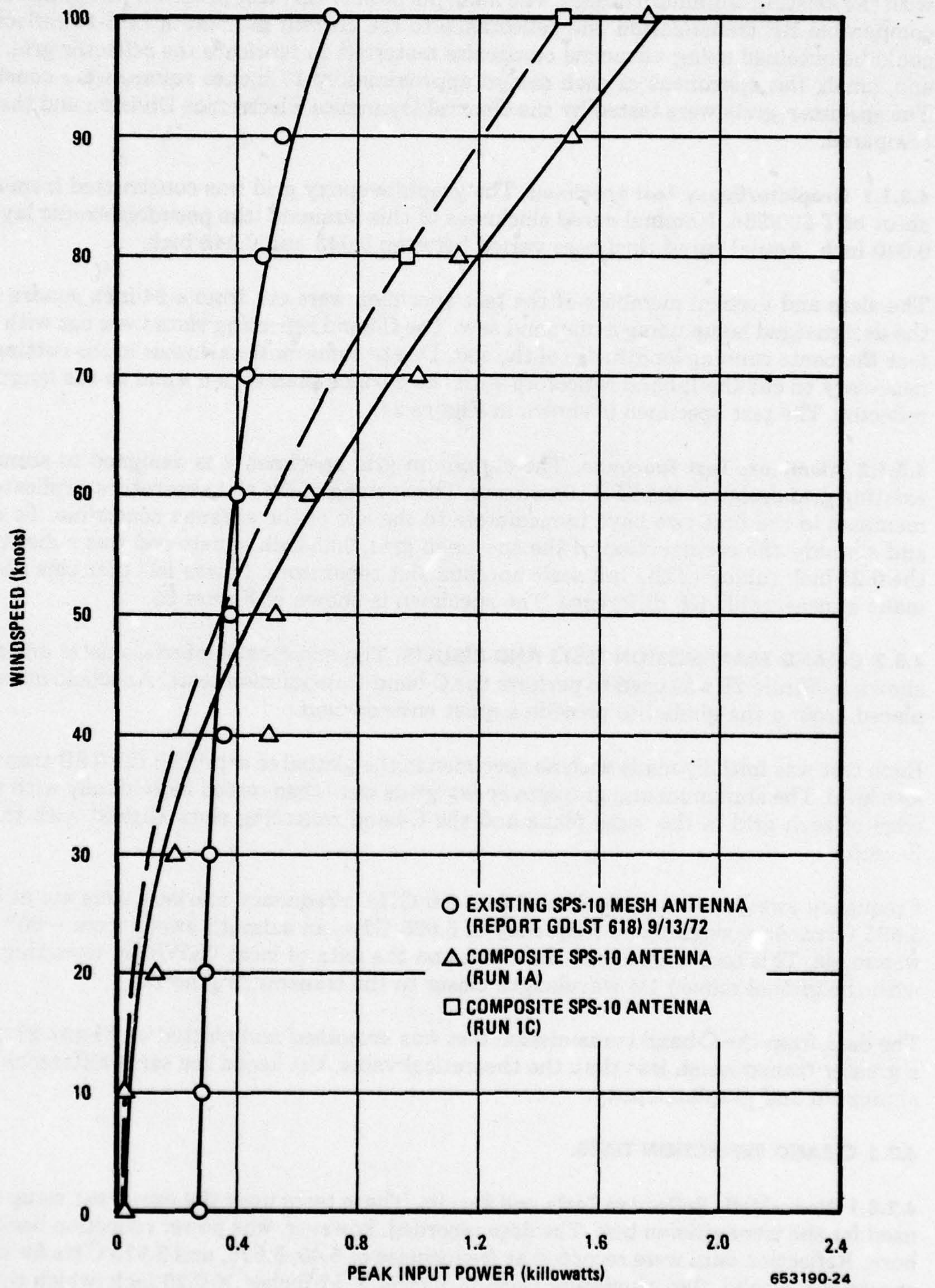


Figure 23. Peak input power versus airspeed plot

with the existing aluminum design. The main purpose of this test program was to indicate that comparable RF transmission and reflectance to the current aluminum SPS-10 reflector grid could be obtained using advanced composite materials to fabricate the reflector grid. To this end, small, flat specimens of each design approximately 17 inches square were constructed. The specimen grids were tested by the General Dynamics Electronics Division and the results compared.

4.3.1.1 Graphite/Epoxy Test Specimen. The graphite/epoxy grid was constructed from an 8-ply sheet of T-300/934. Nominal cured thickness of this laminate (the pseudoisotropic layup) was 0.040 inch. Actual cured thickness varied between 0.043 and 0.045 inch.

The slats and vertical members of the test specimen were cut from a 24-inch square sheet of the designatged layup using a diamond saw. The C-band reflecting slats were cut with the surface filaments running lengthwise of the slat. Due to some material losses in the cutting, it was necessary to cut the L-band reflectors with the surface filaments normal to the length of the reflector. The test specimen is shown in Figure 24.

4.3.1.2 Aluminum Test Specimen. The aluminum grid specimen was designed to simulate the existing grid design of the SPS-10 antenna. The spacing of the slat separators duplicated those members in the first two bays immediately to the left of the antenna centerline. To expedite and simplify the construction of the specimen grid, 0.25-inch square rod was substituted for the 0.25-inch tubing of the full scale antenna slat separators. It was felt that this should not make a measurable RF difference. The specimen is shown in Figure 25.

4.3.2 C-BAND TRANSMISSION TESTS AND RESULTS. The microwave interferometer arrangement shown in Figure 26 was used to perform the C-band transmission tests. Anechoic material was placed around the gimbal to provide a quiet environment.

Each test was initially made with no specimen in the gimbal to establish the 0 dB transmission loss level. The aluminum and graphite/epoxy grids were then tested individually with the front edge of each grid in the same plane and the C-band reflecting slats aligned with the source E-vector.

Frequency sweeps were made from 5.0 to 6.0 GHz. Frequency markers were set at 5.45 and 5.625 GHz. At a single fixed frequency of 5.625 GHz, an azimuth sweep from $-60°$ to $+60°$ was made. This test determined the effects on the data of local VSWR by repeating the test with the gimbal moved 1/4 wavelength closer to the transmitting horn.

The data from the C-band transmission test was smoothed and plotted on Figure 27. It shows a greater transmission loss than the theoretical value, but keeps the same difference between aluminum and graphite/epoxy.

4.3.3 C-BAND REFLECTION TESTS.

4.3.3.1 Mono-Static Reflection Tests and Results. These tests used the same test setup that was used for the transmission test. The data recorded, however, was power reflection back into the horn. Reflection data were recorded at frequencies of 5.45, 5.625, and 5.825 GHz for three test specimens: a solid, flat, aluminum plate 17 inches × 17 inches × 0.25 inch (which served as a reference), the aluminum grid, and the graphite/epoxy grid.

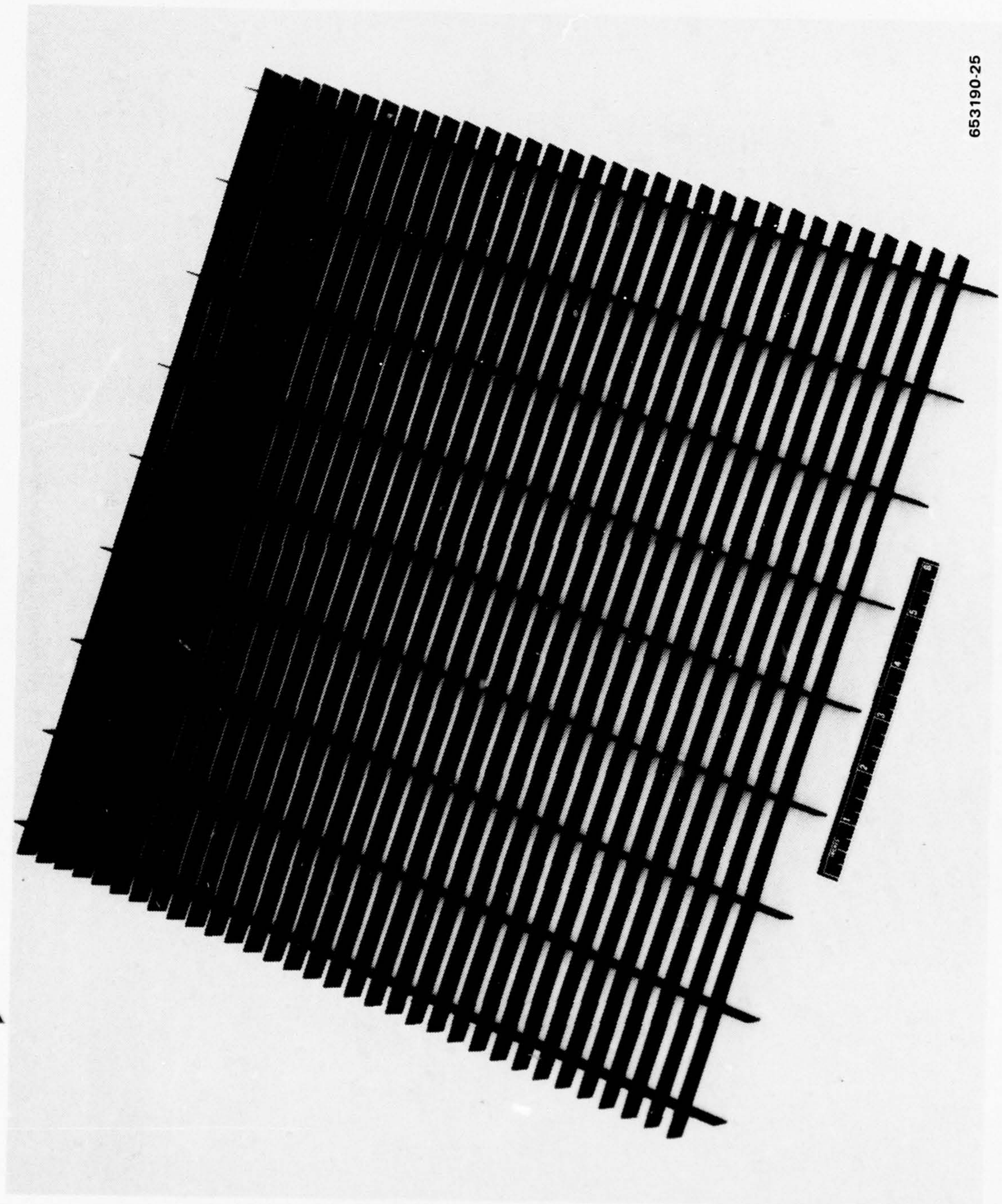


Figure 24. Graphite/epoxy grid specimen

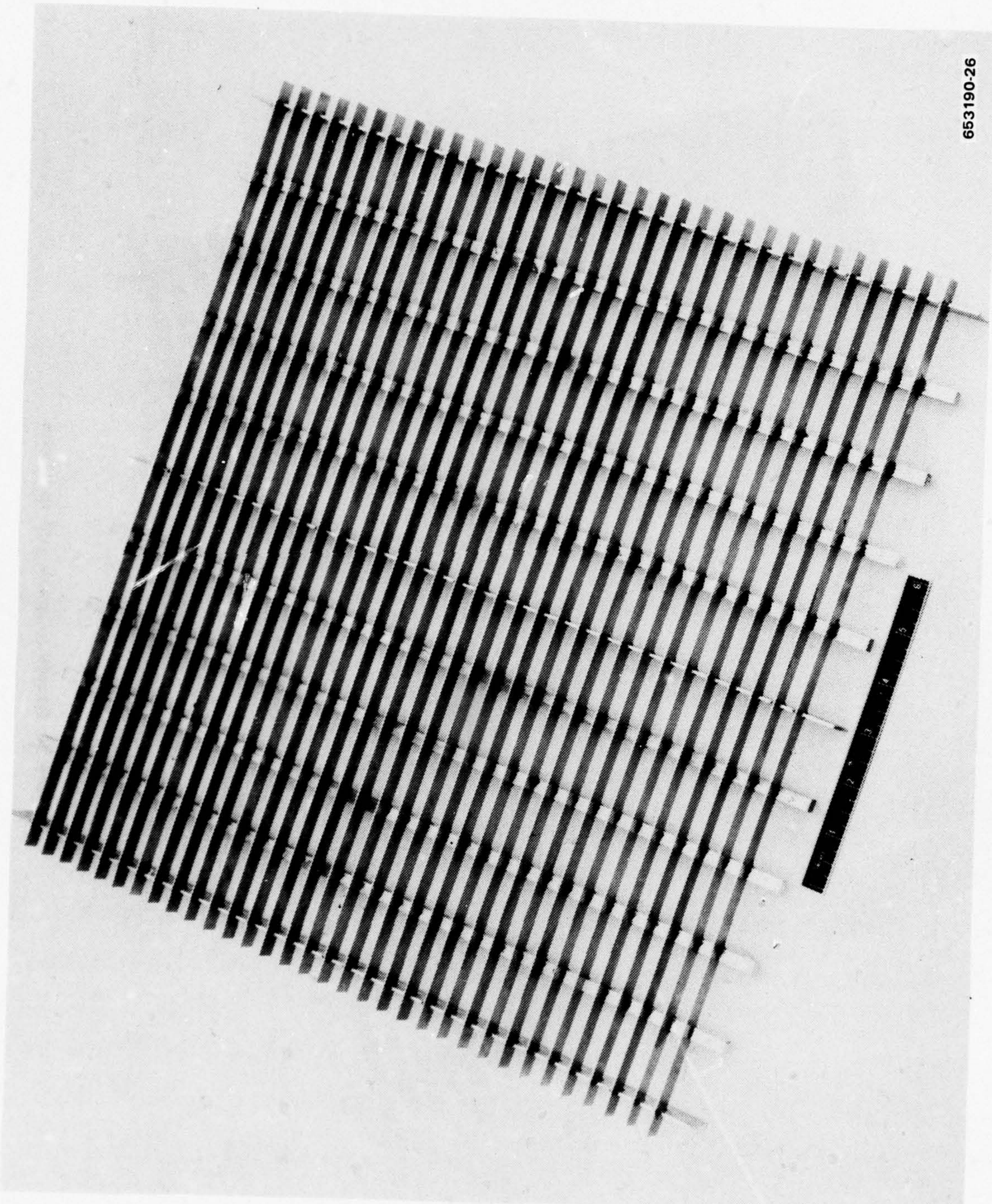


Figure 25. Aluminum grid specimen

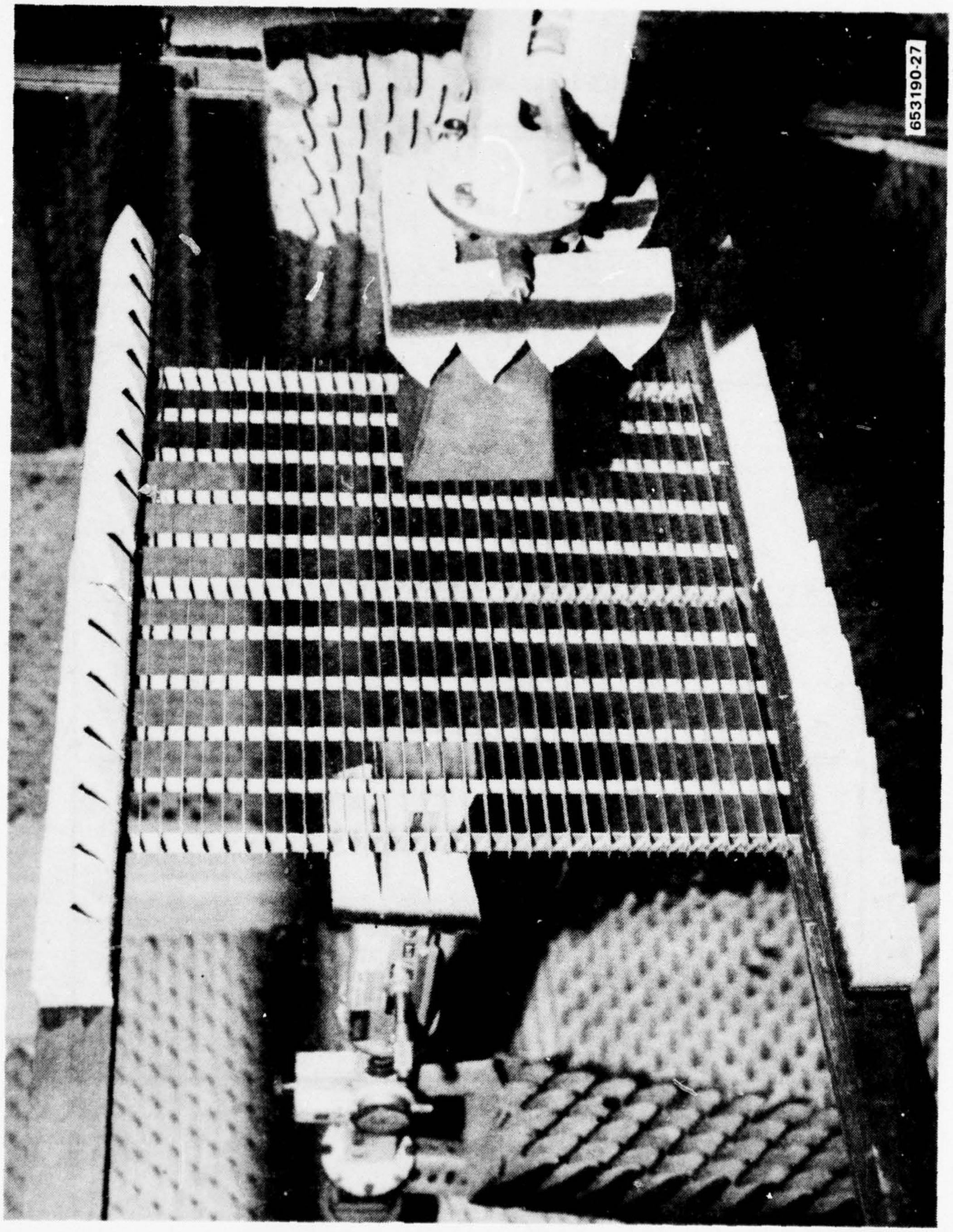


Figure 26. Microwave inferometer with aluminum grid installed

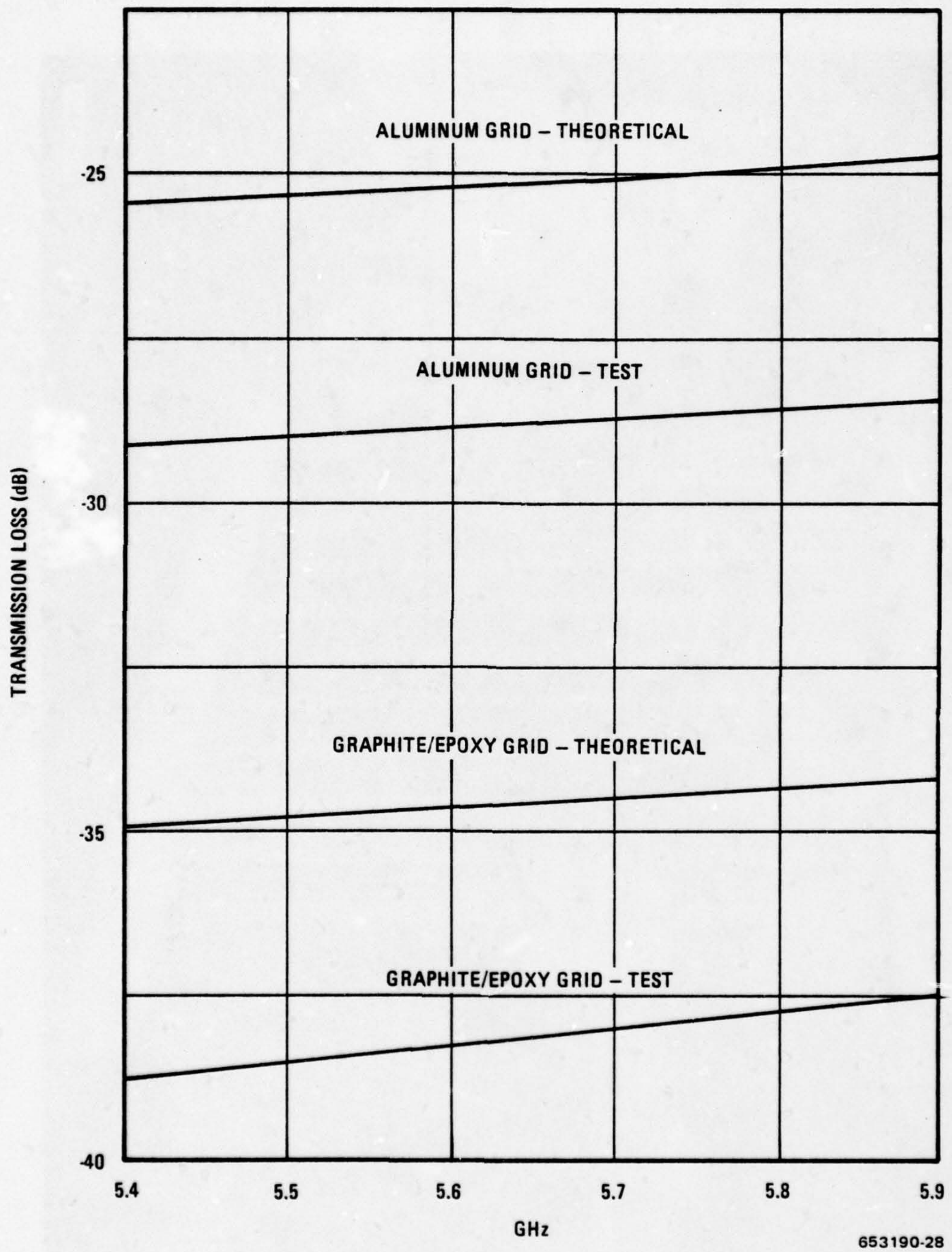


Figure 27. Actual versus theoretical transmission loss - C-band

This tabulation shows comparison results of the two grids to the solid aluminum plate:

Frequency (GHz)	Aluminum (ΔdB)	Graphite/Epoxy (ΔdB)
5.45	+0.1	0.0
5.675	0.0	0.0
5.825	+0.1	0.0

4.3.3.2 Bi-Static Reflection Tests. These tests used the same equipment as the previous tests with a different arrangement for the pickup horn. The horns were arranged for a 26° incidence and reflection angle. The test arrangement is shown in Figure 28. Reflection data was recorded for the three specimens at the same fixed frequencies, 5.45, 5.62, and 5.825 GHz.

In these tests, the gimbal was rocked in both azimuth and elevation to ensure that a peak measurement value was obtained.

This tabulation shows comparison results of the aluminum and the graphite/epoxy grids with the solid aluminum plate:

Frequency (GHz)	Aluminum (ΔdB)	Graphite/Epoxy (ΔdB)
5.625	0.0	−0.1
5.45	+0.2	−0.1
5.825	0.0	−0.2

4.3.4 L-BAND TESTS.

4.3.4.1 Transmission Tests. Using the test setup diagrammed in Figure 29, with the transmission signal return introduced at Port B, transmission data were recorded using, in order:

a. Empty gimbal

b. Solid, flat aluminum plate

c. Aluminum grid

d. Graphite/epoxy grid.

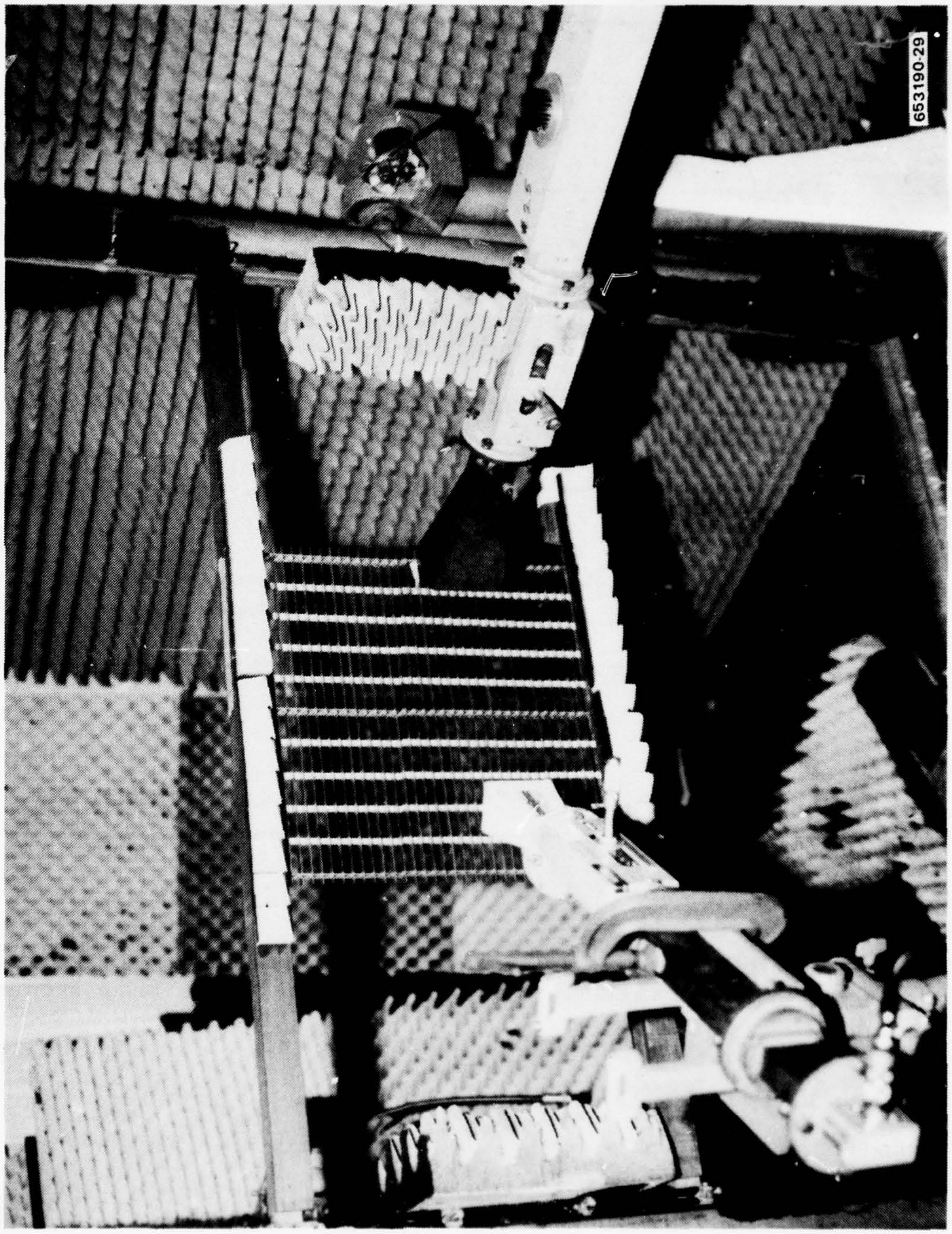
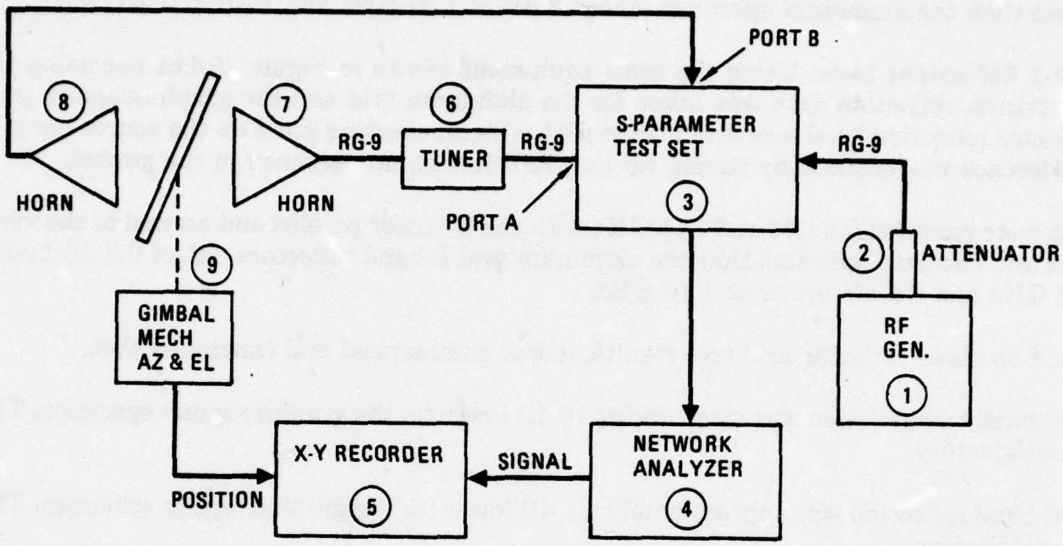


Figure 28. Bi-static reflection (aluminum grid)



ITEM		DESCRIPTION	SERIAL NUMBER	E-NUMBER
1	HP-612A	RF GENERATOR	004-02064	9E05528
2	HP-8491A	10 dB ATTENUATOR	11471	–
3	HP-8745A	S-PARAMETER TEST SET	1517A01276	–
4	HP-8410A	NETWORK ANALYZER	1144A02267	7E02166
5	HP-7030A	X-Y RECORDER	93301485	9E03095
6	DS-109	TUNER-DOUBLE STUB WEINCHEL	7282	1E08876
7 & 8	CA-2	POLARAD HORN ANTENNAS 1.0 – 2.4 GHz	211	9E04510H
9	GD/ ELECTRONICS	GIMBAL-MECHANISM	–	–

653190-30

Figure 29. Transmission and reflection measurement apparatus L-band 1.02 and 1.10 GHz

An azimuth sweep from −60° to +60° was performed at 1.02 GHz and at 1.10 GHz. E-vector polarization was vertical and parallel to the vertical reflectors on the grid. This test had considerable energy reaching the pickup horn, even with the solid aluminum plate in place. The test was able to prove, however, that the graphite/epoxy specimen had considerably less attenuation than the aluminum specimen (about 2 dB at 1.02 GHz and 1 dB at 1.10 GHz).

4.3.4.2 Reflections Tests. Using the same equipment shown in Figure 29 but not using the B port return, reflection data was taken for the aluminum grid and the graphite/epoxy grid. A reference reflection level was established with a metal shorting plate on the source horn. Low interference was ensured by tuning for low VSWR with no specimen in the gimbal.

Data were recorded for 1.02 and 1.10 GHz with the E-vector parallel and normal to the vertical reflector. The data indicates that the aluminum grid L-band reflectors reflect 0.2 dB better at 1.02 GHz and 0.6 dB better at 1.10 GHz.

Based on these reflector grid test results, it was summarized and concluded that:

a. C-band transmission was measured at 10 dB lower for the graphite/epoxy specimen. This is satisfactory.

b. C-band reflection was approximately 0.1 dB lower for the graphite/epoxy specimen. This is satisfactory.

c. L-band transmission was measured as 1 to 2 dB lower for the graphite/epoxy specimen. This is satisfactory.

d. L-band reflection was 0.2 to 0.6 dB less for the graphite/epoxy specimen. This also would be improved to a satisfactory level by reducing the vertical number spacing to 1.60 inches.

Results of these tests were used in designing the full prototype composite reflector unit. Improvement in the L-band performance due to the modified spacing of the vertial members was demonstrated in the electrical performance test.

4.3.5 PROTOTYPE REFLECTOR PERFORMANCE TEST. The specific effort of these tests is to determine the antenna patterns for both C- and L-band. The test specimen, the graphite/epoxy reflector, was mounted on a Navy-supplied SPS-10 spider and feed system assembly. This assembly was then mounted on a three-axis pedestal, which put the antenna about 15 feet above the median ground level. The motorized pedestal was located near a small structure housing the receivers and plotting equipment. Figure 30 shows the antenna mounted on the pedestal and the receiving equipment in the background. The source antennas were mounted on a building at an elevation of 50 feet above median ground level and a distance of 970 feet from the receiving site. The list of test equipment used is shown in Table 8. Reflector performance tests were conducted at the Electronics Division Antenna Range.

The test procedures run are detailed in Section of Appendix A of the Structural and Electrical Test Results Report. C-band tests were made only at the frequency of 5,637 MHz; L-band tests were made at 1020 MHz and 1100 MHz. At all frequencies, the gain was determined by comparison with the standard gain horns listed in Table 8.

Figure 30. Composite SPS-10 reflector on Electronic's division test range

After gain determination, horizontal plane patterns were made for ±180°, ±30°, and ±5° for C-band, and ±180 and ±30° for L-band. Vertical plane patterns were made from −10° to +30° for all frequencies.

TABLE 8. COMPOSITE SPS-10 ANTENNA ELECTRICAL TEST EQUIPMENT LIST

C-Band Test Equipment	Manufacturer	Model	Serial No.
Source Antenna	GD/E		
Source Generator	HP*	618B	335-03813
Frequency Meter	HP*	5245L	544-06527
Variable Attenuator	(IF Attn of Receiver)		
Crystal Mixer	SA**	14-3-45	None
Receiver	SA**	1710	340
Recorder	SA**	1520	9E05164
Gain Standard	SA**	12-3.95	296
L-Band Test Equipment			
Source Antenna	GD/E		
Source Generator	HP*	612A	004-02064
Frequency Meter	HP*	5245L	544-06527
Crystal Mixer	SA**	14-3-45	None
Receiver	SA**	1710	340
Recorder	SA**	1520	9E05164
Gain Standard	SA**	12-1.1	157

*HP — (Hewlett-Packard Co.)
**SA — (Scientific-Atlanta)

4.3.6 ANALYSES OF RESULTS

4.3.6.1 C-Band. The C-band data was compared with the preliminary specification SHIPS-F-5824 as modified 25 July 1977. All specification values were met with the following exceptions:

a. A single side lobe exceeded the −30 dB requirement by 2 dB at about −4°. This appears to be due to an asymmetry, which is thought to be a feed system problem. The reflector is known to be symmetrical.

b. Two lobes exceed the −35 dB requirement and a number of them exceed the −45 dB level. These do not have the appearance of side lobes and are thought to be reflections from nearby objects. The graphite/epoxy grid was proven to have very high-transmission attenuation in a previous test and readable back lobes are not expected. The low altitude of the antenna, the irregularity of the terrain, and the proximity of objects and structures would not prevent the formation of readable reflections below −35 dB.

4.3.6.2 L-Band

a. 1020 MHz. Due to the wider beam of the source antenna and the wider beam of the standard gain horn for L-band, ground reflections did affect the gain determination. A conservative approach in calculating gain would be to take a point 3 dB below the maximum horn reading for reference. This approach would given a gain of 15.6 dB for the 1029 MHz frequency which is below the specified value of 16.75 dB. It can be concluded that the absolute gain for 1020 MHz is correct but is difficult to measure in the particular location. All other required pattern data were within the specified values for 1020 MHz.

b. 1100 MHz. The same ground interference problem for the gain determination was present for the 1100 MHz frequency. In this case, however, the conservative approach gave a 17.0 dB gain, which is above the required 16.75 dB. All pattern data for this frequency are within the specified limits.

SECTION 5

APPLICATION EVALUATION

The basic technical objective of this program is to evaluate the applicability of graphite/epoxy composite materials in Naval shipboard systems. To this end, the reflector grid and backup structure for the SPS-10 antenna system was selected as the design base for the applications evaluation effort. A graphite/epoxy reflector grid was designed and fabricated by Convair and a limited number of tests on the finished product were conducted before delivering it to NOSC, San Diego. The ultimate application evaluation study of course will be in-service testing that will evaluate how well the primary objective of reducing operation and maintenance costs is met.

Preliminary to an in-service application study, a thorough review has been made of all data and technology gained from this program to assess the applicability of graphite/epoxy structures to other Naval antenna systems. This review includes the following areas: 1) RF performance, 2) structural test performance, 3) weight comparisons, 4) fabrication cost evaluation, 5) life cycle and maintenance, 6) corrosion resistance, 7) repairability, and 8) other considerations.

Finally, a survey was conducted of Naval antenna systems that show promise for continued use and that could benefit from the technology developed from this program.

5.1 RF PERFORMANCE

The applicability of graphite/epoxy as a material having transmission and reflection characteristics comparable to the existing aluminum design was evaluated in two phases. They are: The Graphite/Epoxy Grating Transmission and Reflectance Test, and The Reflector Electrical Performance Test. Discussion and description of the test setup, procedure, and results are presented in Section 4.

The grating test results indicated the C-band performance for the graphite/epoxy grid to be satisfactory and the L-band performance, with respect to the transmission particularly, to be considered unsatisfactory. We decided that the latter deficiency could be corrected by reducing the spacing between the vertical members. This conclusion was proved to be correct in the electrical performance test for the full graphite/epoxy reflector. The antenna patterns taken on the graphite/epoxy SPS-10 unit do conform to the requirements of the preliminary SHIPS-F-5824 document dated, 25 July 1977. Even though there were difficulties in obtaining the L-band data due to ground reflection, the data taken indicates proper performance of the reflector.

5.2 STRUCTURAL PERFORMANCE

5.2.1 PRELIMINARY REFLECTOR STATIC STIFFNESS. The composite SPS-10 unit was designed to a maximum deflection of ±0.25 inch when subjected to a uniform 70g static load. This load case envelopes the static and dynamic requirements of MIL-STD-167, the shock requirements of MIL-S-901, wind loads resulting from 100-knot winds, and over pressure resulting from

nuclear blast. Reflector response to the preliminary low-level, midspan load case shown in Figure 31 indicates that the composite SPS-10 unit is approximately 2-1/2 times stiffer than the aluminum SPS-10 unit in the parabolic plane.

5.2.2 REFLECTOR DYNAMIC STIFFNESS. After a thorough and complete analysis of the data collected during the vibration sweep tests, we concluded that the critical resonant frequencies for the composite SPS-10 reflector and antenna system are as shown in Table 9.

TABLE 9. CRITICAL RESONANT FREQUENCIES OF COMPOSITE SPS-10 ANTENNA

Mode	Frequency (Hz)	Direction	Description
1	6-7	Θ_Z	Torsional Z-Axis
2	9-10	Θ_X	Torsional X-Axis
3	13	Θ_y	Torsional Y-Axis
4	15-16	X	Translation X-Axis
5	25	Θ_Z	Torsional Z-Axis
6, 7, 8	33	X, Y, Z	System resonance
	33		Complex resonance — more than one axis translation or rotation simultaneously

5.2.3 WIND DRAG. Low-speed wind tunnel tests were conducted on the composite SPS-10 unit as part of the performance test plan. The purpose of the tests was to determine the effects of wind load on the rotational drive power requirements of the antenna and to confirm structural integrity. Wind speeds were varied from 10 to 100 knots with a desired one-half hour duration test at 100 knots.

Description of these test procedures and their results are described in Section 4 and also in the Structural and Electrical Test Report, which was submitted for approval 1 August 1979. Plots of the input current and input power versus airspeed data, presented in Figures 22 and 23, show that a lower level of input current and power is required to operate the composite SPS-10 unit then the aluminum unit in airspeeds under 50 knots. But above 50 knots, the wind drag increases considerably and the input current and power increase significantly. The wind drag characteristics could be reduced by including wind holes and reduced flange widths for all members of the support structure. But, due to the complexity of the geometry of this SPS-10 unit, the effect of these modifications on the wind drag characteristics could only be evaluated accurately by a wind-tunnel test.

5.3 WEIGHT COMPARISON

Table 10 presents a weight comparison between the existing aluminum SPS-10 reflector and two composite SPS-10 reflectors, the experimental prototype fabricated under this program,

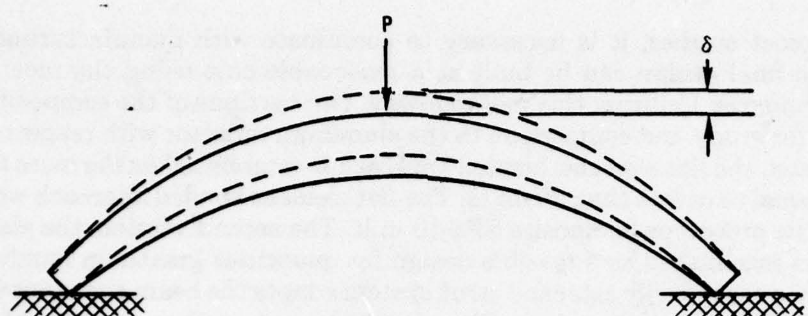


Figure 31. Preliminary reflector static stiffness test

and a production model based on the technology gained in this program. A weight savings of over 11 pounds (14%) is realized by our experimental prototype SPS-10 reflector with an additional 9 pounds (12% additional, 26% total) savings in a production model composite SPS-10 reflector. This additional weight savings can be developed by incorporating wind/lightening holes and a more material-efficient design into a cocured support structure.

TABLE 10. WEIGHT COMPARISON OF COMPOSITE AND ALUMINUM SPS-10 REFLECTORS

Reflector Component	Experimental Composite SPS-10 (lbs)	Production Composite SPS-10 (lbs)	Production Modifications
1. Reflective Grid	20.4	20.4	None
2. Support Structure	36.5	30.5	Windholes, stiffeners. Basic redesign for cocured structure
3. Strut System	8.5	6.0	Composite tubes and fittings
4. Finish Coating	1.5	1.0	No aluminum to protect
Total Composite Wt	66.9	57.9	
Existing SPS-10 Wt	78	78	
Wt Savings	11.1 (14%)	20.1 (26%)	

5.4 COST STUDY

In conducting cost studies, it is necessary to coordinate with manufacturing personnel to ensure that the final design can be built at a reasonable cost using the most cost-efficient fabrication techniques. Utilizing this methodology, two versions of the composite SPS-10 unit are considered for study and comparison to the aluminum reflector with respect to production costs. One version, the flat element, bonded approach is established as the more feasible design for quantities equal to or less than 20 units. The flat element bonded approach was used for the fabrication of the prototype composite SPS-10 unit. The second version, the elastomeric tooling approach, is established as a feasible design for quantities greater in number than 20. In either approach, a secondarily attached strut system adapts the beam structure to the existing metal spider at three support points. The attached strut system consists of aluminum or graphite/epoxy tubes that provide support to the beam structure at four points, i.e., at each end of the two center vertical members. Special bolted fittings attach the struts to the beam structure at these four locations.

Evaluation of the costs associated with the prototype composite SPS-10 unit indicates that program costs can be broken down as nonrecurring costs that were incurred during the design, fabrication, and testing of the first prototype unit and as recurring costs associated with the fabrication of a second prototype SPS-10 reflector under identical conditions to the original unit. The recurring costs can be classified as either fabrication costs or supporting function costs. Thus, based on the costs associated with the prototype SPS-10 unit, cost to fabricate a second composite SPS-10 unit using the same design and tooling aids and not conducting the performance tests would be approximately $69K as shown for Unit No. 1, Table 11. If it is decided to fabricate more reflector units, the cost per unit would be reduced due to a learning curve in the manufacturing area. We could anticipate a 95% learning curve in the fabrication details tasks and a 90% learning curve for the assembly costs. Cost per unit and accumulative costs based on these learning curves for five units as an example are also shown in Table 11. The figures used are based on the 1979 labor rates of the special projects laboratory technicians.

TABLE 11. DOLLAR COST SUMMARY TO FABRICATE ADDITIONAL SPS-10 PROTOTYPE UNITS

	Fabrication		Supporting Costs	
Unit No.	Fabrication Details Unit Cost/Cumulative Cost (dollars)	Final Assembly Unit Cost/Cumulative Cost (dollars)	Management, QA, Matls, etc. Unit Cost/Cumulative Cost (dollars)	Total Cost/Unit (dollars)
1	31,678/31,678	21,495/21,495	16,117	69,290
2	30,094/61,772	19,364/40,841	16,117	65,557
3	29,204/90,976	18,189/59,030	16,117	63,510
4	28,589/119,565	17,411/76,441	16,117	62,117
5	28,121/147,686	16,831/93,272	16,117	61,069
Total (dollars)				321,543 (Ave: 64,309)

GDC-SPS-79-001

Large quantity fabrication requires elastomeric tooling for cost-effective production. In this approach, the entire beam support structure is fabricated in one operation. All joints in this version are formed by the layup pattern of the prepreg material and by resin flow. Pressure is applied during the cure by the expansion of the rubber. This version does not differ functionally from the flat element bonded design used for the prototype unit, but it weighs slightly less because of the deletion of gusset plates and shear blocks and the application of a more material-efficient design. We have successfully demonstrated this tooling approach on other similar programs.

Since each production design presents its own unique problems that must be thoroughly evaluated before an accurate production cost estimate could be made, only past trends and experienced predictions can be presented at this point.

Based on past programs using elastomeric tooling approaches by Convair and other companies in the composite article production industry, fabrication and assembly costs are reduced by approximately 40% for the first production unit and 50% for the 100th production unit using elastomeric tooling/cocured assembly techniques. Also, since manufacturing time is greatly reduced, the recurring program management cost per unit is reduce. Table 12 shows these basic trends.

TABLE 12. EXPECTED PRODUCTION UNIT TRENDS BASED ON PAST PROJECTS AT GENERAL DYNAMICS

Function	Recurring Dollar Cost for Production SPS-10 1st Unit	100th Unit
Program Management and Liaison	9,000	3,000
QA	2,100	1,750
Fabrication and Assembly	33,000	27,750
Shipping	300	300
Labor Total	44,400	32,800
Material	4,200	4,200
Total	48,600	37,000

These cost studies indicate that the average cost for five (5) composite units would be $64.3K for the prototype design and $48.6K for the production design.

Comparatively, the latest estimate (July 1979) for fabricating six (6) aluminum SPS-10 reflector units to the existing design is approximately $11K per unit. With the high demand for aluminum by the aerospace and auto industries and its limited availability, it is reasonable to anticipate this cost to continually climb.

On the other hand, the cost of T300/934 has continually dropped over the past five years with its increased use. For example, it has dropped from an approximate price of $350/lb in 1967 to $35/lb in 1978 when ordered in bulk.

Table 12 does not include two nonrecurring costs: engineering design/analysis and tooling. Based on the cost analysis in Table 11, the engineering budget for the design and analysis of a production reflector unit and its elastomeric tooling would be similar to engineering cost in the prototype unit program. The tooling task will incur a much larger initial cost than the engineering design/analysis task. Based on estimates from other programs using elastomeric tooling, the initial tooling costs for a cocured production unit is in the range of 10 to 15 times the cost of the production unit. Using this rule-of-thumb, the initial tooling cost would be in the $500 to $600K neighborhood. This cost would be amortized over the entire lot of 100 units. The additional unit cost of approximately $6K brings the total unit cost of the 100th production unit to approximately $44K.

5.5 LIFE CYCLE AND MAINTENANCE COMPARISON

The present life cycle of the aluminum SPS-10 unit ranges from 6 to 8 years and, in some cases, can be as short as 16 months. The life cycle of the graphite/epoxy antenna is unlimited in theory, and can be expected to exceed 20 years. This performance duration is anticipated under the typical stack gas/salt spray, heat shipboard environment.

One of the problems encountered during the life cycle of a SPS-10 reflector unit, aluminum or graphite/epoxy, is the task of antenna maintenance. Since its location on shipboard is in such an area of difficult accessibility, maintenance must be performed in port at scheduled intervals. We assume that the ship must be scheduled to be in port long enough to remove the aluminum SPS-10 reflector for sanding, priming, painting, etc., every 18 months to two (2) years. Each aluminum SPS-10 reflector is scheduled for a complete restoration program every three (3) years. Such a timetable may conflict with a ship's overall performance efficiency.

The graphite/epoxy SPS-10 unit should require no restoration program and no scheduled maintenance. Only occasional inspection is necessary for emergency repairs and/or maintenance.

5.6 CORROSION RESISTANCE

The corrosion protection system used for the SPS-10 reflector was formulated to provide resistance to salt spray and marine environments. The system meets or exceeds the requirements of MIL-E-16400. The materials and processes used in the system are capable of providing protection in severe saline conditions. This approach ensures that reflector defects, maintenance procedures, or other nonroutine exposure of the antenna system to the shipboard environment will cause no corrosion problems.

The antenna system consists essentially of three materials: Thornel 300/Hysol EA934 graphite/epoxy, 6061 aluminum alloy, and G10 glass/epoxy.

The graphite/epoxy composite is a highly inert, corrosion-resistant material. When joined together or to another inert material, such as titanium, little or no galvanic corrosion occurs. Tests have also shown that the composite is insignificantly affected by ultraviolet exposure. Although most resin systems absorb moisture to an equilibrium condition of about 1 to 2 percent over long periods of time, no change in properties occur below 225F. A characteristic of graphite/epoxy composite to be recognized, however, is that it is an inert material and when

coupled to a less inert material promotes the corrosion of the less nobler metal. When coupled to aluminum, for example, th potential difference can be more than one volt. This is enough driving force to cause considerable corrosion of the anodic aluminum. Several studies have been made in recent years by industry, the Navy, and the Air Force to determine the significance of this problem. It has been generally concluded that the static and fatigue behavior of graphite/epoxy — aluminum joints are unaffected by a marine environment as long as conventional military corrosion protection systems are used. Convair has run many tests that verify this conclusion.

The materials and processes were chosen to give optimum corrosion protection to the antenna structure. It can be safely exposed to a shipboard environment because of the surface treatments, sealants, and coatings used.

Protection of the aluminum alloy parts begins with a sulfuric acid anodic coating per MIL-A-8625, Type II, Class 1. These parts are anodized after welding and before any mechanically fastened parts are installed. All parts, including graphite/epoxy, aluminum, and G-10 glass/epoxy, are then finished with one coat of MIL-P-23377 epoxy polyamide primer and two coats of MIL-C-81773 polyurethane topcoat using film thicknesses and techniques of application specified in MIL-F-18264.

5.7 REPAIRABILITY

The current state-of-the-art technology for composite materials includes repairability concepts for structural restoration of resin matrix composite structures that have been developed and experimentally validated for some of the commonly used composites with damage exceeding 100 square inches.[1] Although thorough experimental testing has not been conducted on many different composites, it is generally agreed that the repairability techniques are applicable to T300/934 graphite/epoxy. Static and fatigue tests on several specimen sizes and materials, including the effects of temperature and moisture on repair joint efficiency, have been conducted throughout the composite material industry. For composite materials, the anisotropy and tendency to delaminate around the fractured area, plus the effects of moisture, oil, paint stripper, and fuel must be taken into account during the repair procedure method. The technology that has resulted from materials and process studies, as well as the environmental effects on composite laminates, has led to repair techniques that are representative of real environments and equipment conditions, and that are capable of restoring the basic strength and stiffness of the parent laminate.

Certain basic materials data must be defined before a repair can be rationally attempted. These data are on: 1) the parent material, 2) the patch material, and 3) adhesive as follows:

a. Parent Material Properties. The basic parent material used throughout the SPS-10 antenna program is T300/934 graphite/epoxy tape prepreg cured at 100 psi into laminates of the (0/±45/90) family.

b. Patch Material Properties. The prepreg selected for the repair of the T300/934 parent laminates is T300/934. This choice was based on the handling qualities of prepreg, moisture

[1] Reference Northrop work

resistance, and amenability to vacuum pressure curing. The desire to be able to use only vacuum pressure for the cocuring of all repairs comes with the requirement for on-antenna implementation. Vacuum-bag cocuring prelcudes the need for an autoclave and for increased pressures when a repair must be made on the antenna.

In comparison to the properties of the parent material, the strengths of the vacuum-cured T300/934 $[(\pm 45/0/90)_2]_s$ laminates nominally suffer a significant reduction due to the lower cure pressure. However, this strength reduction is not insurmountable in the repair joint design since: patch plies are added over and above the amount removed by damage, and the patch laminate strength rarely is the critical parameter in joint performance.

c. Adhesive Properties. To be compatible with the 265F maximum service temperature criterion adopted, a 350F curing structural adhesive was selected for use with the graphite/epoxy patch material. This adhesive, FM-400 flim at 0.070 lb/ft^2, is cocured with the patch at the time the scarf joints are implemented, and acts in a state of nearly pure shear.

Composite repair design concepts are encompassed by six unique repair configurations as shown schematically in Figure 32. These configurations, including several variations within each of the generic types, have been analytically developed and, for the most, part, experimentally examined for structural efficiency via static and cyclic load tests under previous studies. The static testing includes the effects of temperature and moisture, while the joint reliability is being assessed by random excitation to specific levels of maximum tensile strain.

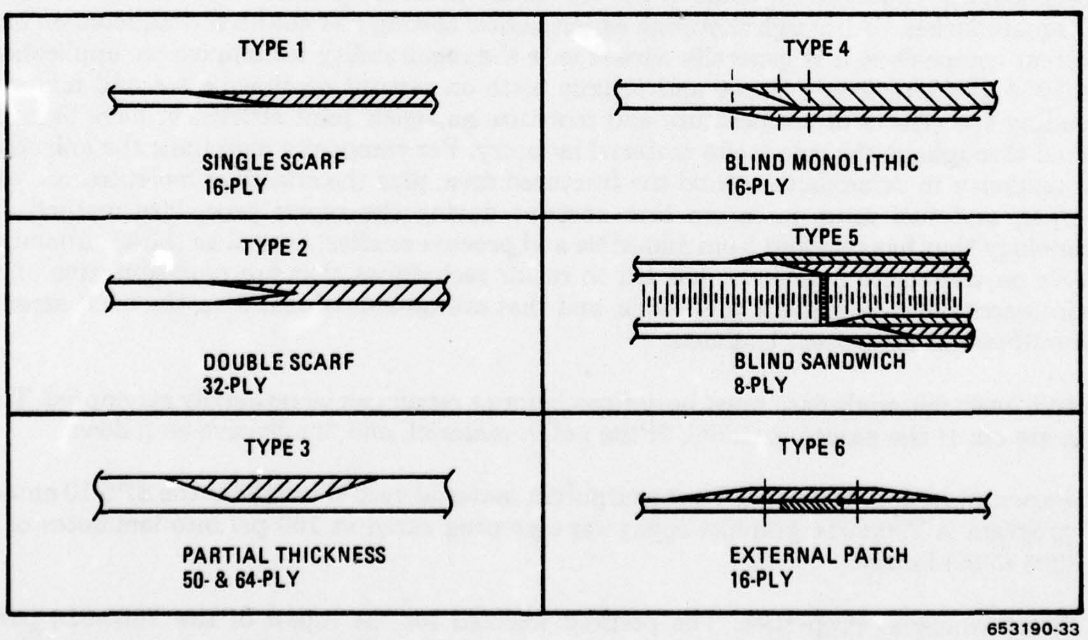


Figure 32. Repair joint concepts

In all cases, the details of each repair configuration are based on three prime considerations:

a. Various degrees of accessibility or, more appropriately, lack of accessibility that can be expected in service on the damaged structure.

b. Structural efficiency of the repair, particularly as regards patch layup and adhesive joint configuration.

c. Material removal, rework, and repair techniques that can be realistically achieved at depot-level facilities

All of the repairs shown in Figure 32 use cocured repair laminates, and most employ adhesively-bonded scarf joints. Repair experience to date has shown this to be a realistically achievable repair. The scarfed configuration is obviously structurally efficient, and can be made on a repair basis by grinding and sanding with appropriate tools and tooling aids. Workmanship tolerances cannot be expected to be up to normal production standards, but the cocuring procedures will significantly reduce fitup problems that otherwise would be unacceptable.

Damage requiring immediate attention at sea where cocured repaired techniques could not be applied can be repaired in place using either a "dry" 0°/90° wooven graphite cloth or precured T300/934 flat stock patches and an epoxy resin that cures at room temperature. The epoxy resin is stored in two parts, resin and hardener (catalyst), that would be mixed and used as required. The patch material would be packaged as a shipboard repair kit. Repair procedures would require cleaning the damaged area prior to repair and applying pressure to the repair patch during adhesive cure. This emergency repair configuration is structurally adequate to complete the ship's scheduled mission, but should be replaced by a permanent cocured repair at the first convenient time.

5.8 OTHER CONSIDERATIONS

The effect of other environmental conditions on composite material properties and performances must be considered in evaluating the applicability of composites material for Naval antenna systems. These effects are discussed below in the following paragraphs.

a. Lightning Strike. Graphite filament organic matrix composites are susceptible to lightning damage, and do not provide electromagnetic shielding. Exposure of an unprotected graphite laminate to direct lightning strike can result in severe laminate damage, such as burning or rupture.

   Advanced composite laminate structures require lightning strike protection if the component is an exterior or moldline surface of the ship. Several basic lightning strike protection systems that have been tested and found suitable are:

   1. Aluminum flame spray approximately 6 mils thick.
   2. Aluminum foil 5 mils thick.
   3. Aluminum wire mesh (120 × 120 mesh, 0.003-mil wire diameter; and 200 × 200 mesh, 0.0021-mil wire diameter).

Protected composite test panels that have been exposed to 200-kiloampere simulated lightning discharges without composite damage.

Unfortunately, the standard protective systems necessary to guard against lightning strike damage all consist of external conductive aluminized coatings of one type or another and, consequently, are vulnerable to the same problems that the existing SPS-10 experience.

Lightning strike protection would have to take the form of lightning rods that are detachable for transportation and are able to withstand the vibratory and shock environment of the ship.

b. Carbon Fiber Release. Since graphite fibers have a low density and small diameter, they can be carried aloft in a fine plume or otherwise can remain airborne for considerable time, and hence can be transported from the scene of an accident or fire to the site of electrical or electronic equipment. Furthermore, because graphite fibers are electrical conductors, they can cause short circuits, equipment malfunctions, or possible fires if they should get into electrical or electronic equipment. This problem was studied and reported on by NASA Langley Research Center on 31 October 1978.

They concluded that the public risk due to accidental release of carbon fiber from air transport aircraft is small. This would also be applicable to shipboard antennas. Further work is required to increase our confidence in these estimates.

c. Environment Exposure. Table 13 shows the effect of environment exposure on the strength properties of graphite/epoxy laminates.

d. Survivability and Vulnerability. Evaluation of the survivability and vulnerability of the graphite/epoxy to ballistic fire has been limited. A study evaluating the damage that results from ground handling and foreign object impact during service use and maintenance activities has been conducted at Northrop Corporation.[1] Tests were conducted to investigate the effects of foreign object velocity, angle of incidence, size, and material on the impact damage to thin monolithic graphite/epoxy panels. The specimens were impacted by a projectile fired from a gas gun and quantitative measurements of the damage were made. Gas gun impacts were conducted on 8- and 16-ply monolithic panels during this study. Impact objects included spherical glass, steel, and ice projectiles at velocities ranging from 52 feet per second to 480 feet per second. Damage results from these tests were localized in the immediate impact area. This indicates that impact damage of low-velocity projectiles should have minimal effect on the structural and electrical functions of the antenna until repair procedures can be implemented.

A separate series of gas gun projectile impacts tests at velocities up to 2452 feet per second on thicker laminates was also conducted to observe the effects of significantly higher velocities on thicker laminates. Even though results show a significantly large area of damage by material cracking and delamination, the repair techniques described in 5.7 are applicable. We concluded that for high velocity ballistic impact on a thin monolithic graphite/epoxy panel, the damage should be a very localized, clean tear-out hole. The survivability and vulnerability of the reflector to damage caused by ballistic fire is dependent

[1] Reference Northrop work

TABLE 13. EFFECT OF ENVIRONMENT ON STRENGTH PROPERTIES OF GRAPHITE/EPOXY LAMINATES

Environment	Effect
Humidity exposure — 30 days exposure to 95 — 100 percent relative humidity at 120F	Exposure to 95 percent relative humidity at 120F for 30 days seemed to have little effect on the room-temperature tensile-strength of graphite/epoxy unidirectional laminates. However, the compression strength was reduced by about 12 percent.
Fuel immersion — JP-4 for 7 days at room temperature	There was little or no degradation in room-temperature strength properties due to exposure to JP-4. Graphite/epoxy, however, showed about a 6 percent reduction in room-temperature flexure strength. No degradation in elevated temperature strength properties were observed.
Hydraulic oil immersion — 7 days at room temperature	No degradation in room or elevated temperature strength properties were noticed for graphite/epoxies due to immersion in hydraulic oil.
Anti-icing fluid (Methanol) immersion — 7 days at room temperature	About a 4 percent reduction in room-temperature tensile strength and a 5 percent reduction in short beam shear strength of graphite/epoxy were observed after immersion in anti-icing fluid (Methanol). No degradation was noticed in elevated-temperature strength properties.
Salt spray — 30 days	A 12 percent reduction in room-temperature compression strength was observed after 30 days of exposure to salt spray. No degradation in tensile strength was noticed, although a 4 percent reduction in room-temperature tensile modulus was observed.
Distilled water immersion — 30 days at room temperature	A 6 percent reduction in both room-temperature tensile and compression strengths of graphite/epoxy was noted after 30 days immersion in distilled water.
Thermal cycling — 3 to 20 cycles: −65 to 72F; 72 to 350F; −65 to 350F	Little or no degradation in tension, compression, short beam shear, or flexure strength was noted at room temperature for graphite/epoxy laminates. Furthermore, with the exception of a 7 percent reduction in flexure strength, no degradation was observed for graphite/epoxy at elevated temperature after thermal cycling.
Thermal shock — 3 cycles: −65 to 350F	No degradation in room-temperature strength properties was observed after thermal shock exposure.
Ultraviolet Radiation	Properly finished composite structures are not subject to ultraviolet deterioration.

on the location of the damage and the operating conditions the reflector is subjected to during its damaged condition. A direct hit on a joint by ballistic fire should be the only impact damage condition that might limit the operation of the antenna.

5.9 NAVAL ANTENNA SYSTEM SURVEY

A survey was conducted of Naval antenna systems that show promise for continued use and which could benefit from the technology developed from this program. The basis of information for this survey was NAVSHIPS 0967-177-3050, "Shipboard Antenna Systems, Antenna Data Sheets," Volume 5. This publication provided a ready source of information of the electrical and mechanical characteristics of individual shipboard antenna systems.

The evaluation of the applicability of composite materials to other antenna systems was based on six categories. They are:

a. Electrical input requirements.

b. Accessibility of shipboard antenna location.

c. Structural size and configuration of antenna.

d. Possible weight savings.

e. Operating modes.

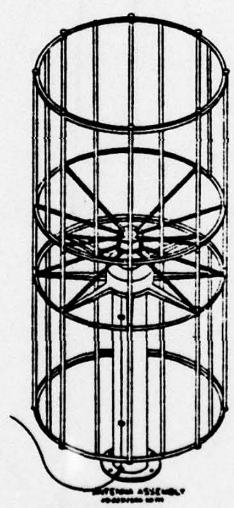
f. Current and future usage of the candidate antenna.

Based on these criterion, evaluations of the four (4) most promising candidate antenna systems for composite material application, described in Figures 33 through 36, are presented in Table 14.

ANTENNA ASSEMBLY AS-2231/SRA-60(V).

a. TYPE/USE. - The AS-2231/SRA-60(V) antenna is a broadband omnidirectional biconical dipole. It is a component of the AN/SRA-60(V) Antenna Coupler Group. The antenna consists of a center support post and two cylindrical cage type radiating elements. A teflon insulator for isolating the two sections of the dipole is located on top of the support column. The antenna transmission line is connected to the upper radiating element at the insulator. The vertical members of the upper and lower cones are connected by a fiberglass insulator for mechanical rigidity and vibration damping. The AN/SRA-60(V) coupler group is supplied in either a four or eight channel configuration. The eight channel configuration requires the installation of two AS-2231/SRA-60(V) antennas.

b. PHYSICAL CONFIGURATION.



c. PHYSICAL DIMENSIONS. - (1) Height - 156 inches O.A.
(2) Diameter - 48 inches O.A.
(3) Weight - 409 lbs.

d. FREQUENCY RANGE. - 30 to 76 MHz.

e. INPUT IMPEDANCE/VSWR. - 50 ohms nominal, VSWR not greater than 3:1 over frequency range.

f. RF POWER RATING. - 400 watts avg. 1600 watts PEP.

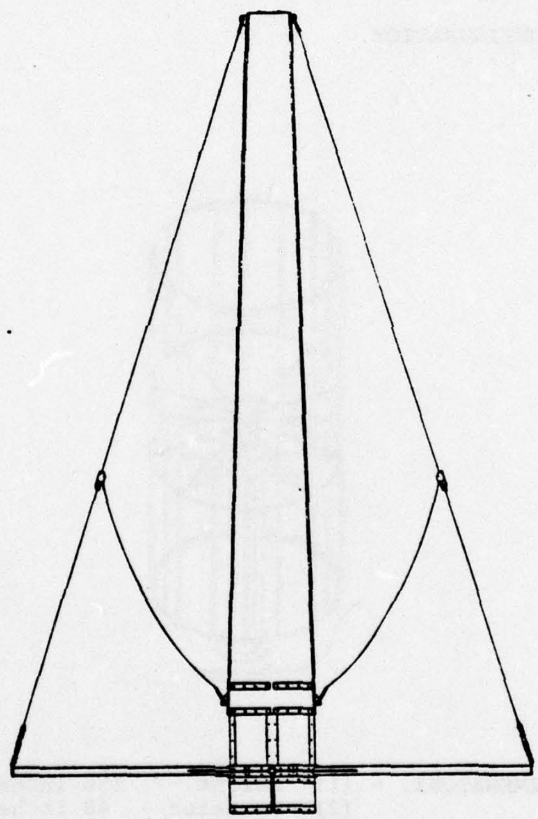
653190-35

Figure 33. Candidate antenna system for composite material application — AS-2231/SRA-60(V)

ANTENNA AS-2806/SRC.

a. TYPE/USE.- The AS-2806/SRC is an omnidirectional trussed monopole antenna. The antenna consists of a box type aluminum mast with four wire rope trusses from the top to outriggers at the base of the antenna. The wire trusses are insulated from the outriggers by fiberglass rods. The base insulator is an integral part of the mast section. The AS-2806/SRC may be used with any transmitting and/or receiving equipment capable of operating within its frequency range and rf power handling limitations. It may be operated in a vertical, tilted, or horizontal position as in an aircraft deck edge installation.

b. PHYSICAL CONFIGURATION.



c. PHYSICAL DIMENSIONS. - (1) Height - 162-3/4 inches O.A.
(2) Width - 96-1/2 inches.
(3) Depth - 96-1/2 inches.
(4) Weight - 85 lbs.

d. FREQUENCY RANGE. - 10 to 30 MHz.

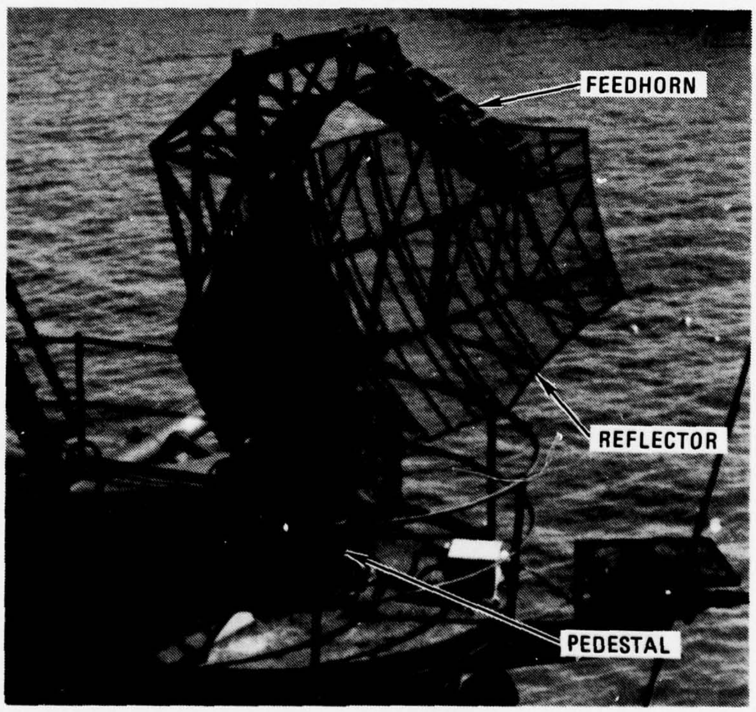
653190-36

Figure 34. Candidate antenna system for composite material application — AS-2806/SRC

ANTENNA AS-1138/SPS-40

a. TYPE/USE. - The AS-1138/SP is a unit of the AN/SPS-40 Radar Set. The antenna consists of a tubular constructed reflector unit, dual feedhorn unit and a pedestal unit. The pedestal houses the drive motor, gear assembly, ship heading marker switch, synchro transmitter and rotary joint. The feedhorn contains an integral IFF dipole. Radar and IFF signal connections are made to the pedestal unit. The reflector is a parabolic type. The feedhorn assemblies are designed so that the radar signals and IFF signals are cross-polarized during transmission. Because of this cross-polarization of radiated energy, the receiver echoes are easily separated into their respective inputs. An antenna safety switch type SA-755/U, located in proximity to the antenna, is used to remove power from the antenna motor circuitry so that the antenna cannot be rotated and RF radiated while personnel are in the area.

b. PHYSICAL CONFIGURATION.



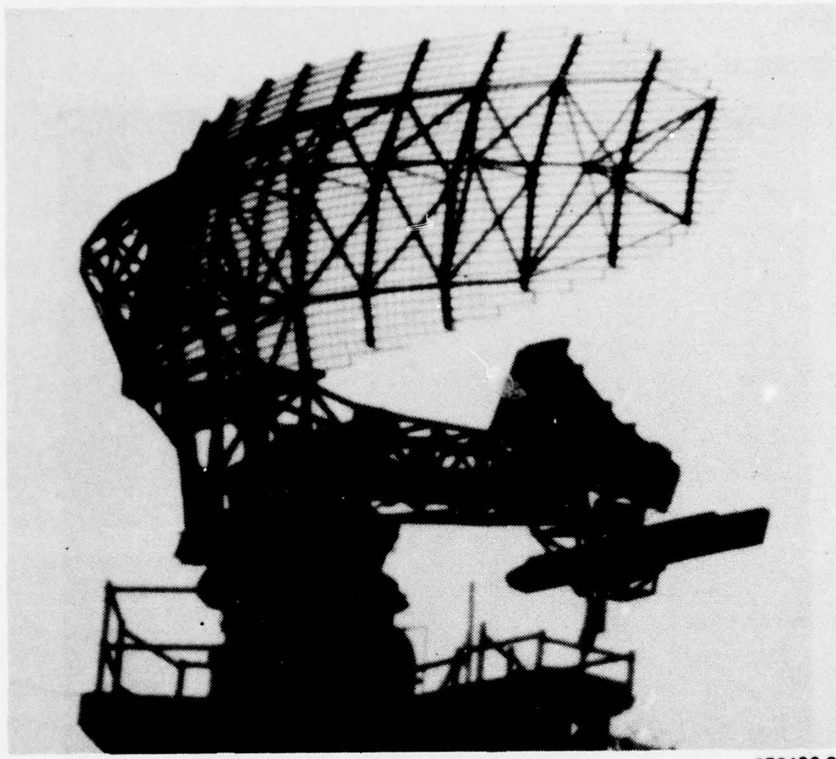
c. PHYSICAL DIMENSIONS. - (1) Height - 138 inches.
(2) Width - 213-1/2 inches.
(3) Depth - 106-1/4 inches.
(4) Weight - 1425 lbs.

d. FREQUENCY RANGE. - Refer to NAVSHIPS 93821(A).

e. RF POWER RATING. - 200 kilowatts, peak.

653190-37

Figure 35. Candidate antenna system for composite material application — AS-1138/SPS-40



653190-38

Figure 36. Candidate antenna system for composite material application - AS-3080/SPS-49

TABLE 14. EVALUATION OF CANDIDATE ANTENNA SYSTEMS

	AS-2231/ SRA-60(V)	AS-2806/ SRC	AS-1138/ SPS-40	AS-3080/ SPS-49
Candidate component applicable for composite design	Center Support mast and cylindrical cage	Center mast	Reflector and feedhorn unit	Reflector and feedhorn unit
Electrical input requirements	Requirements satisfactory. Input points reinforced w/metal conductor.	Requirements satisfactory.	Requirements satisfactory. Metal screen for reflective surface.	Requirements satisfactory for reflector. Low loss design for feedhorn.
Shipboard location	Limited accessibility for LCC 19 and 20 Class ship	Anywhere on shipboard	Below SPS-10 level. Limited accessibility	Below SPS-10 level. Above ship deck 30 to 40 feet. Limited accessibility.
Structural configuration	Simple, tubular	Rivet assembled box cross-section	Double plane parabolic truss, very complex	Double plane parabolic truss, very complex
Weight savings	Very good, possible 25 to 30%	Very good, possible 20 to 25%	Good	Good
Operating modes	Stationary	Stationary, meets Class A shock	Rotational	Rotational
Future usage	Good	DD963 Class only, new antenna, widely used	Newer type of antenna, widely used	Newer type of antenna, widely used
Summary	Excellent candidate, simple design	Excellent candidate, simple design	Good candidate, similar effort as SPS-10. Antenna size may dictate larger design and analysis effort	Good candidate, similar effort as SPS-10. Antenna size may dictate larger design and analysis effort

SECTION 6

CONCLUSIONS

The overall program objective of providing a lightweight, noncorrosive, advanced composite SPS-10 antenna have been met and verified by wind, vibration, and electrical testing to the required military specifications. The feasibility of graphite/epoxy for Naval antenna systems was demonstrated to be satisfactory.

Results from the wind tunnel, vibration, and electrical performance tests were completely satisfactory and met all performance military-standard requirements specified in the contract. Even though the vibratory test results indicate resonant frequencies below 50 Hz, design modifications and the application of high stiffness materials such as GY-70/5208 could produce an antenna with a higher resonant frequency threshold. A lower weight, lower maintenance, lower life-cycle cost reflector unit was achieved. Note that these cost and weight advantages were realized even in the prototype design, which is a very conservative design and fabrication technique unit. Real and parametric data relative to merits, cost, and the applicability of graphite/epoxy technology for updating performance in the surface-ship marine environment were derived.

SECTION 7

RECOMMENDATIONS

Based on results of the design, fabrication, and testing efforts conducted during this study, together with the further application evaluations studies performed on the basis of this work, we make the following recommendations:

a. A thorough set of electrical performance tests be performed on the composite SPS-10 reflector at a test range free from ground reflections to get true antenna patterns and gain.

b. Subject the composite SPS-10 reflector unit to actual shipboard environment conditions for an extended period of time. Then perform simple structural and material property tests to evaluate the effects of shipboard environment.

c. Solicit from Naval agencies, additional candidates that would most benefit from the composite material technology developed in this program.

d. Perform a detailed study on the actual cost for the design and fabrication of a large number of reflectors, say 100. This will give a more representative feeling for the advantages of graphite/epoxy for Naval antenna systems.

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Arlington, Virginia 20360
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Gary Tremblay,
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Navy
Antenna Systems

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